Highlights in Space

PROGRESS
IN SPACE SCIENCE, TECHNOLOGY
AND APPLICATIONS

1992

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Progress in space science, technology and applications

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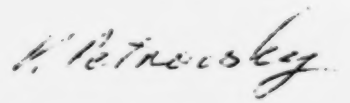
FOREWORD

Over the past decade space activities have become increasingly integrated into the everyday lives of all people and have become the focus of expanding international cooperation. This review of recent developments in space science, technology and applications is intended to provide information on these developments to a broad international audience. First published in 1992 as part of United Nations activities undertaken for International Space Year, the publication seeks to increase the awareness of all countries of the benefits of space activities.

During the past year there have been dramatic changes in the international political situation which has prompted great changes in the level and scope of international cooperation in space activities. Many of the cooperative agreements established in 1992 and the collaborative projects launched are detailed in this publication. Many of these programmes focused on observing the Earth from space and were conducted as part of International Space Year, the theme of which was "Mission to Planet Earth." The goal of these programmes is to assist scientists in the understanding of Earth and the natural processes that sustain life. Such an understanding is crucial as humanity makes a collective effort to improve its management of natural resources in order to ensure that they are developed in a manner that will sustain life on Earth far into the future.

As illustrated in this publication, many other areas of space science, technology and applications are also playing an important role in economic and social development. Virtually all countries of the world routinely use space satellites for telephone service, television and radio broadcasting, and weather forecasting. Important advances in space life science are paying dividends in the form of improved medical care on Earth and experiments conducted in space in are contributing to industrial development in many countries. Finally, space exploration continues to stimulate the imagination and enrich our knowledge of ourselves and the world we live in.

It is hoped that this publication will make a significant contribution to United Nations efforts to disseminate information on space activities and to highlight the benefits they provide to all countries of the world.



Vladimir Petrovsky
Under-Secretary-General for Political Affairs

INTRODUCTION

This publication has been compiled from two reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space. The first part of the report, on space technology and applications, was prepared by the International Astronautical Federation (IAF). The second part, which focuses on space science, was prepared by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Many of the most prominent international experts from many countries have contributed to this comprehensive and authoritative survey. The information it contains reflects the wide range of space activities currently being conducted in many national and international space programmes. A list of contributors is located at the end of the report. This publication is being circulated only in the language in which the reports were prepared and submitted.

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PART ONE:

HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS 1992

I. OVERVIEW

By far the most important feature affecting space technology and applications in 1992 was the reduction in scope of the programmes in spacefaring nations due to budget constraints. Cutbacks in major development activities in the United States. included yet another redesign of Space Station Freedom, curtailment or elimination of research and development on new launch systems, elimination or reduction in scope of several scientific spacecraft and observatories, downsizing of the Earth Observing System and its data system, and virtual elimination of funding for human space exploration. In the Commonwealth of Independent States (CIS) the transition of many space programmes to a self-supporting mode has forced major reductions of activity in many areas, and economic constraints on government programmes have forced the curtailment or cancellations of major programmes, most notably future Buran flights and Energiya launches. In Europe budget cuts have resulted in the cancellation of the Hermes spaceplane and the free-flying Columbus space laboratory, as well as reductions in scope of the remaining laboratory facilities aboard Space Station Freedom.

On the positive side, 1992 has seen rapid growth in both the number and the depth of cooperative activities in space technology and applications. Many unprecedented agreements have been signed among agencies of the Commonwealth of Independent States, the United States, the European Space Agency (ESA), several European nations, China, India, and Japan; they involve major programmes such as space stations, launch vehicles and systems, and satellite constellations. Astronauts and cosmonauts from many nations now fly routinely in space, and formerly sacrosanct national assets are being offered for cooperative programmes. Serious discussions have even been initiated on both bilateral and multilateral sharing of missile defense technology and missile-attack warning systems.

Although many budding commercial enterprises are also suffering from global economic pressures, the opening by the International Telecommunications Union's (ITU) World Administrative Radio Conference of new opportunities for communication to mobile terminals via low-altitude communication satellites represents a whole new area for major expansion in space and related ground systems and services. This action has accelerated the current wave of mobile-terminal services being conducted via existing satellite systems, both for communications and position location. Similarly, many new applications have become available due to the launch this year of new radar remote-sensing satellites by European countries, Russia, and Japan.

One of the more exciting events of the year was the spectacular rescue of the stranded satellite Intelsat 6F-3 by three astronauts aboard the United States Space Shuttle Endeavor during that orbiter's maiden flight. The rescue demonstrated unequivocally that ground simulation, although useful, cannot replace in-space testing and demonstration of space systems and operations. And, despite the budgetary constraints that faced all the world's space programmes, phenomenal results were obtained by various scientific spacecraft in astronomy and astrophysics, solar-terrestrial physics, atmospheric sciences, and studies of the solar system. Moreover, spacecraft launched this year are expected to maintain and expand the current surge of new data and information that many have called the second Golden Age of space science and exploration.

II. SPACE TRANSPORTATION

A. Current Launch Activities

The total number of launches decreased significantly from 1990 to 1991. The former Soviet union conducted 59 launches in 1991 compared to 75 in 1990; the United States conducted 19, down from 27 in 1990, and Arianespace flew eight. The successor state to the Soviet Union, the Commonwealth of Independent States, launched six spacecraft during an eight-day period in January 1992: two military satellites, a Progress resupply mission to Mir, and three Global Navigation Satellite System (GLONASS) satellites. By the end of September 1992, the Commonwealth of Independent States had conducted 33 launches.

The 31 August launch of the Satcom C-4 satellite aboard a McDonnell Douglas Delta-2 marked the 35th consecutive success of Delta launchers since 1986; the 36th and 37th were launches of a United States Global Positioning System (GPS) satellite on 9 September and Germany's 1400-kg DFS-3 Kopernikus on 12 October. That launch brought Delta's success rate to 99.9 per cent or 80 successful launches out of 81 attempts.

The General Dynamics (United States) Atlas II had a successful maiden flight on 7 December 1991, when it launched the third Eutelsat 2 from Cape Canaveral. Its second and third successes occurred on 11 February and 2 July with the launch of military satellites. Increased propellant capacity (14 per cent in the Atlas first stage and 23 per cent in the Centaur upper stage) and booster-engine upgrades (10 per cent in thrust and 1.5 per cent in specific impulse) increased Atlas-II's payload capacity 25 per cent over that of Atlas I (which, incidentally, was used successfully to launch Hughes Communications' 1415-kg Galaxy 5 on 13 March). Atlas IIA, the first of which was used to launch the Intelsat K satellite on 9 June, featured additional Centaur upgrades in avionics as well as main-engine thrust (25 per cent) and specific impulse (5 per cent), enabling it to place over 2,800 kg into a geosynchronous transfer orbit (GTO). The Atlas

IIAS, which uses solid-propellant boosters to increase payload capacity into GTO to 3700 kg, is currently in production for first launch in 1993.

On 13 March Atlas was selected to launch the first two Inmarsat-3 satellites in late 1994 and 1995. The United States government later issued its approval for the Russian Proton to compete for launch of the third Inmarsat-3, which is being built by the United States company GE Astro Space.

In attempting to launch a Hughes Galaxy 1R communications satellite on 22 August, the Centaur upper stage of an Atlas-1 vehicle suffered its second failure. In both cases the turbopump on one of the Centaur's two RL-10 hydrogen-oxygen engines did not come up to speed. Investigators of the first failure, which occurred in April 1991, concluded that the cause was probably foreign objects in the propellant lines. Nitrogen ice was thought to be a potential culprit. The Commonwealth of Independent States Zenit launcher experienced its third consecutive failure on 5 February after a launch from the Baikonur Cosmodrome in Kazakhstan.

An Ariane 44L successfully launched Japan's Space Communications Corporation Superbird B and the 21-nation Arab Satellite Communications Organization's Arabsat 1C into orbit on 27 February. Ariane's 50th flight in April initiated a new operational phase for Arianespace. Not only did it mark the first of a 50-vehicle production lot, but it cut six days from the 35-day Ariane 44L launch preparation period. Launch of the Hughes Galaxy 7 aboard an Ariane 42P (No. 54) on 28 October marked the 18th consecutive success of Ariane launchers since July 1990. Arianespace has scheduled six launches for 1993.

The M-3S-II solid-propellant launcher developed by Japan's Institute of Space and Astronautical Science (ISAS) will be phased out after the Astro-D astronomical satellite is launched early next year. Introduction of the M-5, its larger updated successor with a low Earth orbit payload capability of 1,600 kg compared to the 780 kg capability of the M-3S-II, has been postponed until 1996 due to development problems. The TR-1A sounding rocket successfully launched a microgravity payload containing six microgravity experiments from Tanegashima Space Centre to an altitude of 290 km on 20 August.

China's Long March 3 lifted a domestic communications satellite into the wrong orbit on 28 December 1991 due to failure of its liquid-propellant third stage, which shut down prematurely during its second burn because of a leak in the helium control system. A Long March 2E successfully orbited Australia's Optus-B1 satellite on 14 August after a false start attempt on 22 March (see below).

B. Development Activity

The new United States National Launch System (NLS), originally a joint effort by NASA and the United States Air Force to develop the next-generation workhorse launcher for the United States continued to be impeded by budget constraints imposed by the United States Congress. Current plans call for initial development of a single-engine launcher able to lift 9-tonne payloads to low Earth orbit, though these plans have been put in jeopardy due to action taken by the United States Congress in late 1992. A larger, multi-engine version in the 23 tonne range will be developed later using the same engines, avionics, and ground processing systems. Both configurations could be equipped with solid-propellant boosters to more than double their payload capabilities. Activity this year focused mainly on development of a new, reliable, low-cost 2,900-kN thrust hydrogen/oxygen engine called the Space Transportation Main Engine. The smaller NLS vehicle would use a single engine to power its first stage; the larger one would use a four-engine half-stage and two engines in the first-stage core. Although United States Air Force space officials have stated that all their launches are to be transferred to the NLS within 15 years, the programme's progress remains in serious doubt due to budgetary considerations and to differences between NASA, the Department of Defense and the Congress on how the programme should proceed.

NASA in late August reopened studies of STS-C, an all-cargo modification of the Shuttle, formerly named Shuttle-C. Its potential mission would be to relieve the high risk associated with exclusive use of the Shuttle to deploy Space Station Freedom (SSF), using its more than 50,000-kg payload capacity and large payload bay to launch fully equipped modules in five flights (plus five Shuttle flights to carry the astronauts who will assemble the station) over a three-year period beginning in 1996. The current plan calls for 27 Shuttle flights over five years to deploy and assemble the station. The preliminary STS-C concept consists of an in-line payload carrier atop a modified Shuttle external tank, whose boattail is fitted with the three-engine assembly now used on the Shuttle orbiter. The Shuttle's current Redesigned Solid Rocket Boosters (RSRMs) would also be used. The United States is also evaluating use of the Russian Energiya launcher as an alternative, and is considering the tradeoffs involved in placing SSF in a 51.6-degree orbit instead of one inclined at 28.5 degrees. Such a change would allow the use of a Soyuz capsule launched from Baikonur to serve as a back up to the Shuttle for emergency crew use.

Japan's NASDA initiated in August a definition study for a new J-1 launcher designed for cost-effective launch of small payloads (900 kg to low Earth orbit). The 33-meter, 79,000-kg vehicle will use the H-2's 700-kN solid-rocket boosters and the M-3S-II's second and third stages. The J-1's payload can be augmented by 100-200 kg using 2 to 4 solid-propellant strap-on motors adapted from the TR-1 sounding rocket's first stage.

ESA's Ariane-5 development continued on schedule, with completion of long-duration ground firings of the Vulcain cryogenic main engine, successful solution of combustion instabilities in the upper-stage liquid-propellant engine (with acoustic attenuators), and casting of the full-scale (230-tonne) solid-propellant booster rocket. This is the first large solid-propellant rocket ever developed in Europe. Studies of post-Ariane-5 vehicles were initiated this year.

Italy's first test of Zefiro, an experimental new booster stage for the Scout-2, an upgrade to the workhorse United States Scout small-payload launcher, was destroyed by its range safety officer on 18 March about 10 seconds after its launch from Sardinia.

On 20 May India successfully launched its new Augmented Space Launch Vehicle (ASLV) from the Sriharikota Launch Range, orbiting a 106-kg stretched Rohini Satellite Series (SROSS-C) satellite into a low Earth orbit (267 x 433 km). This third ASLV development launch incorporated several modifications based on failure analyses of the previous two ASLV flights in 1987 and 1988. SROSS-C reentered the atmosphere on 14 July. The all-solid-propellant ASLV demonstrated several advanced technologies for India's Polar Satellite Launch Vehicle (PSLV), which uses liquid-propellant engines in its second and fourth stages, and its Geostationary Satellite Launch Vehicle (GSLV). The first PSLV development flight is scheduled for 1993, when it is expected to launch the 1,000-kg Indian Remote Sensing (IRS-1E) satellite into a 900 km orbit. The first development flight of GSLV, which will be able to launch 2500-kg communication satellites into a GTO, is planned for 1995-96.

In December Russia tested a new commercial space launch vehicle based on the mobile SS-25 missile, which is to be designated Start-1. The three-stage, all-solid-propellant SS-25 has a ballistic range of 10,500 km. As a space-launch vehicle, which, like the missile, can be launched from many different locations, it can carry small payloads (350-500 kg) to low orbit. About 270 SS-25s are reported to be available for such missions.

III. UNMANNED EARTH ORBITAL ACTIVITIES

A. Telecommunications

1. Fixed Base Communication Systems

Optus Communications Corporation, which purchased the Australian government's Aussat Pty. Ltd. last November, successfully completed and launched the first of two new satellites (formerly Aussat B-1 and B-2; now Optus B-1 and B-2). Optus B-2 was launched to its geosynchronous transfer orbit by China's Long March 2E on 14 August. The launch was the second attempt to launch Optus B-1; the first was aborted

on the launch pad on 22 March (without damage to the satellite) when the launcher's strap-on boosters were shut down by an incorrect signal.

In January Pasifik Satelit Nusantara of Jakarta, Indonesia purchased the Palapa B-1 satellite, launched in 1981, to provide low-cost service to Japan, South Korea, Hong Kong, and the Pacific island nations. Indonesia's other three Palapa-B satellites will all eventually be sold to Pasifik Satelit. The last of these, Palapa B-4, was launched 13 May aboard a Delta rocket.

Astelit, a joint venture of Italy's Telespazio and Russia's Astra, began international telephone service from Moscow in February and St. Petersburg in March, using the former military communications satellite fleet of eight Raduga spacecraft. In another effort to improve telephone service to and from the former Soviet union, Australia's Overseas Telecommunications Corporation built an Intelsat ground station in Alma Ata, Kazakhstan and trained Kazakh operators in its use. It went into service on 28 February.

At the World Administrative Radio Conference (WARC) held from 3 February to 3 March in Torremolinos, Spain, the Russian delegation proposed a constellation of 36 small satellites called Smolsat (also known as Gonets). It will use a store-and-forward system able to service over 10,000 users with medical information and other data. Westinghouse (United States) is expected to build the Earth-station equipment for the spacecraft, which will be launched in groups of six between 1993 and 1996 on Russian Tsyklon rockets. The first two Gonets satellites, which will serve as bellwethers to evaluate the service and its market potential, were launched into low Earth orbit from Plesetsk by a Tsyklon rocket (along with four military communications satellites) on 13 July. These spacecraft constitute Russia's first commercial-satellite venture.

In September the geostationary-orbit Russian satellite Geizer, originally launched in December 1991 to relay launch orders for nuclear missiles, began commercial service in the Sokol system for private-network communications between the United States and Russia. The satellite can carry 100 telephone conversations at C-band frequencies.

The Eutelsat-2 F4 satellite was modified to accommodate the large new potential markets in Eastern Europe, delaying its Ariane-4 launch (and also that of the Topex-Poseidon radar ocean-observing scientific satellite, which was to follow the Eutelsat launch) from 20 July to 10 August.

On 9 July the multipurpose Insat-2A, the first of India's new Insat-2 series, was launched by an Ariane vehicle. The Insat- 2 satellites, built in India, have about 50 per cent greater capacity than the Insat-1 series, four of which were purchased from Space Systems Loral (United States). The Insat-2 series' Very High Resolution Radiometer also has better resolution than that of the Insat-1 satellites, and they carry a transponder that provides instantaneous alerts for satellite-aided search and rescue. Insat 2A is the first geostationary satellite in the Indian Ocean to have this capability. Insat 2B is scheduled

for launch aboard an Ariane vehicle in 1993. Insat-2C, 2D, and 2E are under construction. France's Telecom 2B, launched aboard an Ariane-4 on 15 April, also went into service for France's overseas territories in June.

Spain's first domestic satellite, Hispasat 1A, was launched 10 September aboard an Ariane 4, accompanied by GE Americom's Satcom C3. The 2200-kg Spanish spacecraft, the first of two, was assembled by Matra Marconi Space in a record 33 months. The two Hispasat satellites' five direct-broadcast channels can be received on antennas as small as 40 cm. Hispasat 1A includes several components built in Spain.

On 16 September Intelsat's board of governors awarded the prime contract for the Intelsat 8 series to GE Astro Space (United States), with an initial order of two satellites to be delivered in September 1995 and January 1996. Intelsat also ordered another Intelsat 7A from Space Systems Loral for delivery in March 1995. The Arab Satellite Communication Organization announced on 2 October that the next two spacecraft in the Arabsat 2 series, the first of which is scheduled for launch in 1995, would be built by Hughes (United States). The new satellites will each carry 20 C-band, two S-band, and 12 Ku-band transponders. Television transmissions to the Arab countries can be received on 60-80 cm dishes.

2. Mobile Communication Systems

Taking action that is expected to revolutionize the satellite communications field, the ITU's 124-nation World Administrative Radio Conference (WARC) in Torremolinos, Spain (3 February to 3 March) approved global frequency allocation spectra for a host of new services to be made available via low-Earth-orbit satellite constellations beginning in October 1993. These include mobile telephones, data-messaging to hand-held receivers, and high-quality radio transmission. The WARC did not unify spectrum allocations for high-definition television, leaving existing regional allocations in place until 2007. The United States Federal Communications Commission subsequently (on 8 April) issued experimental licenses to two 24-satellite low-orbit system operators, Orbital Communications Corporation and Starsys Global Positioning Incorporated, and on 5 August opened the field to United States applicants who wish to connect global satellite systems to wireless (cellular) telephones. The five applicants are Motorola, TRW, Loral Qualcomm, Ellipsat, and Constellation Communications.

Motorola revised its initial concept of the Iridium low-orbit communication system this year, departing from the 77-satellite constellation that gave it its name (the iridium atom has 77 electrons orbiting its nucleus). The new concept cuts the number of orbits from 7 to 6 and the total number of satellites from 77 to 66, each of which will now have 48 spot beams instead of the 37 originally envisioned. The spacecraft mass has been increased from 550 kg to 680 kg.

On 9 January Orbital Communications Corporation (United States) signed agreements with five Latin American nations for mobile satellite services. Brazil, Argentina, Uruguay, Colombia, and Panama joined Canada and Venezuela, which had signed agreements with Orbital in 1991.

Inmarsat 2-F3, launched 16 December 1991 by an Ariane 4, took over service to most of the Pacific area from Intelsat MCS-D and Marisat F3 on 19 January. Inmarsat also introduced in February a new fast-response distress-call system for ships, Inmarsat E, which uses 5-kg buoys to transmit ship locations to geostationary-orbit Inmarsat satellites as soon as they hit the water. The current Cospas-Sarsat system operated by the United States, France, Canada, and the Commonwealth of Independent States uses low-orbit satellites, which are not always within sight of distress transmitters.

On 21 April, the Inmarsat system was utilized by Comsat Aeronautical Services to initiate for the first time global voice-communications service by a United States commercial air carrier, Northwest Airlines. Five other airlines have since outfitted a total of 13 aircraft, mostly Boeing 747s, to ascertain passenger demand for the service. By the end of the year Air France, Japan Airlines, Lufthansa, and United Airlines joined Northwest and Singapore Airlines, which initiated its service in September 1991, in testing the system and its marketability. Direct radio transmission of news, sports, and weather broadcasts to commercial airliners began this summer when Delta Airlines equipped the first of 80 Boeing 757 aircraft to receive the broadcasts from USA Today Sky Radio via GTE Spacenet's GStar-3 satellite. The system uses a small (38-cm) antenna on the aircraft which rotates to track the satellite.

On 2 March American Mobile Satellite Corporation (United States) initiated data transmission and position information services to trucking companies and other customers. The new services, which lag by one year those of Telesat Mobile, the firm's Canadian partner, use Inmarsat satellites to relay data through American Mobile's Washington hub.

In March four mobile satellite service companies agreed to design hand-held receivers employing common specifications, to assure low cost and interoperability. The four signatories were American Mobile Satellite Corporation (United States), Telesat Mobile Incorporated (Canada), Optus Communications Pty. Limited (Australia), and Industrias S.A. de CV (Mexico).

3. Navigation and Position Location

The demand for combined position-location and communications capability soared in 1992 due to rapid expansion of the truck market and the opening of new markets such as fishing fleets and petroleum companies. Qualcomm's OmniTRACS (United States) sold 3,650 mobile communications terminals in the first three months of 1992. It sold less than 1,600 in all of 1991. The United States system uses two satellites 12

degrees apart: GTE G-Star and RCA K2. Euteltracs, operated by Alcatel Qualcomm, began commercial operations in November 1991 and expects to have nearly 3,000 trucks equipped with its system by the end of this year.

Launches of the United States Global Positioning System (GPS) Navstar navigation satellites resumed on 23 February after a 7-month hiatus due to failures on the attitude control systems of existing spacecraft. Four additional GPS satellites were launched this year (all aboard United States Delta-2 rockets), achieving a total orbiting complement of 16 satellites. The full constellation, which will consist of 21 satellites plus three orbiting spares, is expected to be in orbit by mid-1993. A new 110-gram receiver for GPS signals became available 24 April. Manufactured by Garmin International (United States), the GPS-10 receiver measures only 10 cm by 7.5 cm.

The United States Federal Aviation Administration (FAA) in February issued its FAA Satellite Navigation Program Plan for 1992-1997. The plan features a Global Navigation Satellite System, endorsed by the International Civil Aviation Organization (ICAO) in 1991, which will use both United States GPS and Commonwealth of Independent States GLONASS satellites for all civil aviation operations except possibly Category 2 and Category 3 precision approaches. A special FAA task force on satellite navigation recommended on 14 October that the conversion begin in 1993.

On 25 March the American Automobile Association (United States) initiated a year-long test to evaluate information systems installed in 100 automobiles operated by a rental car agency in Orlando, Florida. The systems use data from GPS satellites to provide continuous position "fixes" to both the driver and the Orlando traffic management centre. Another test, using 5,000 automobiles, is scheduled to begin in Chicago next year. Japan estimates that by 1995, 1.6 million automobiles in that country will be equipped with GPS navigation systems.

A unique "first" occurred on 16 June, when a rain-forest creature, a Cameroon elephant named Isabel, was fitted with a satellite-tracked radio collar. Monitored by a United States NOAA satellite 850 km overhead, Isabel has demonstrated that rain-forest elephants have much smaller ranges -- 109 square km -- than savannah elephants in Zaire (1,300 square km).

B. Remote Sensing

1. Earth Observations

On 30 January ESA signed agreements for commercial distribution of data from its ERS-1 radar-equipped research satellite with Canada's Radarsat International (for Canada and the United States), with Italy's Eurimage (for Europe, North Africa, and the Middle East), and with France's SPOT Image (for the rest of the world). By October

ERS-1 had generated and transmitted over 200,000 synthetic-aperture radar images at a rate of about 700 per day, and the distribution time to users had been reduced from several weeks to as little as two hours via Norway's Spacetec, which uses a network of Intelsat spacecraft and ground telephone systems.

On the same date Russia's Almaz Corporation signed an agreement with Hughes STX Corporation (United States) to market, distribute, process, and license in the United States Almaz synthetic-aperture radar data. This marked the first full transition of a former Commonwealth of Independent States government system to a commercial operation. Almaz later signed an agreement with Italy's Eurimage for European distribution rights of Almaz data. Unfortunately, however, the 17-tonne Almaz spacecraft reentered the atmosphere on 17 October and was destroyed.

In March SPOT Image reactivated the retired SPOT-1 spacecraft, owned by the French space agency CNES, to meet increasing demand for images. SPOT-1 was launched in February 1986 and retired in September 1990. It has enough propellant remaining for about one year's service. SPOT-3 is to be launched in 1993, and a new design, SPOT-4, is scheduled for launch in 1996.

The United Nations High Commissioner for Refugees used satellite imagery from SPOT and Landsat spacecraft, collected from October to December 1991, to identify high-fertility farmland areas for resettlement of 350,000 Cambodian refugees. The United Nations Transitional Authority for Cambodia also employed about 100 Very Small Aperture Terminals (VSATs) for use in coordinating the activities of the 22,000 United Nations personnel supervising the refugees' return. Extensive mapping of Eastern Europe using SPOT, Landsat, and ERS-1 satellites was begun this year by the European Commission's Directory for Environment, Nuclear Safety, and Civil Protection. Key environmental problems in the 1.2 million square kms to be surveyed include industrialization of national parks in Hungary, wind tides and movement of sand dunes along Poland's Baltic coast, deterioration of forests due to heavy industry in Czechoslovakia, and pollution due to mining in the "Black Triangle" area of northern Czechoslovakia, southwestern Poland, the Danube, and eastern Germany.

ESA also initiated a programme to upgrade the Lad Krabang ground station in Bangkok, Thailand, to receive ERS-1 data and to build new data-processing facilities there as well as in Jakarta, Indonesia, in Kuala Lumpur, Malaysia, and in Manila, the Philippines. Because this region has heavy cloud cover, the availability of ERS-1's radar images is particularly valuable, as noted below in connection with JERS-1. Additional ERS-1 ground stations are planned for Israel, Taiwan, Kenya, South Africa, and Brazil. Stations in Cotopaxi, Ecuador, in Secunderabad, India, in Alice Springs, Australia, in Hatoyama and Kumamoto, Japan, and at McMurdo Sound in Antarctica are already equipped to receive ERS-1 data.

On 16 April Russia initiated the marketing of Earth images generated by over 30 sensors and cameras aboard the Mir space station. Resolution of the various devices ranges from 5-m to several kilometres, and data can be provided either on film returned by Progress or Soyuz vehicles or electronically via an Intersputnik downlink to Moscow. The first such images were delivered to Germany in August, where Mir's photographs of Leipzig, Halle, and Bitterfeld were used to assess the degree of environmental damage due to industrial wastes. Photos of the Erzgebirge region were also used to evaluate forest damage, and images of the Brandenburg area documented the environmental effects of surface mining of coal.

Japan's Earth Remote Sensing satellite (JERS-1) was launched aboard Japan's last H-1 launcher on 11 February. Its synthetic-aperture radar antenna, key to the 1,400-kg JERS-1's mission, at first failed to open, but NASDA engineers were finally able to unfold it and move it into position on 9 April. During subsequent testing JERS-1 was found to use less propellant than planned, extending its useful life from two to perhaps four years. In August it began using its radar to conduct land surveys, forestry studies, and agricultural assessments, as well as to inventory natural resources, to aid in disaster prevention, and to perform coastal monitoring in the Pacific rim area, where heavy cloud coverage (typically 90 per cent) prevent the use of visible, microwave, and infrared satellite sensors. JERS-1 also carries infrared sensors with 18-m resolution.

The Australian Center for Remote Sensing (ACRES) introduced a new programme, Farm Image, to help Australian farmers analyze their land and plan its use more effectively. The programme, which began in January and uses both Landsat and SPOT images, supplements earlier ACRES projects that track bush fires, monitor the conditions of small lakes, monitor land use in urban growth, and prospect for minerals. A programme jointly supported by Italy and China, to train Chinese personnel in the interpretation of United States Landsat imagery collected by the Beijing ground station, was launched in March at China's National Remote Sensing Center. Italy's Telespazio will provide Olivetti computers, software, and training to the Center.

At a World Forest Watch meeting in Sao Jose de Campos, Brazil, from 27 to 29 May, researchers reported on remote sensing studies which suggest that deforestation of Brazil's Amazon basin was not as serious as earlier reports by the United Nations Food and Agriculture Organization (FAO) had indicated, although the loss rate is still unacceptably high (about 2,000 hectares per hour). The studies used data from NOAA weather satellites, Landsat, SPOT, and initial experimental results from ERS-1 and JERS-1. The Watch, which is an activity organized for International Space Year (ISY), called for lower satellite-image prices and a unified global research strategy that would establish closer cooperation among international and regional agencies.

A one-year test period for a satellite system to help analyze the potential effects of droughts and crop failures on food shortages in Africa began in July. The Direct Information Access Network for Africa (DIANA), an ESA system, allows FAO to

transmit satellite images from its headquarters in Rome via Intelsat to FAO's analysts in Ghana, Kenya, and Zimbabwe.

Another remote sensing programme in Africa, the Southern African Fire-Atmosphere Research Initiative (SAFARI) began in September to attempt to measure the atmospheric effects of savannah burning in Africa, which is conducted routinely by the South African government for land-management and wildlife preservation. Information from land-based, airborne, and satellite sensors will be used to quantify the particulate deposition by smoke and other global warming effects.

2. Atmosphere and Ocean Observations

Just three months after the United States Upper Atmosphere Research Satellite (UARS) was launched (on 12 September 1991) it had mapped the global distribution of chlorine monoxide and confirmed its direct link to depletion of stratospheric ozone. Although shut down for over a month beginning on 2 June due to problems with the solar-array drive motors, UARS's instruments were brought back on line gradually and by 20 July all the spacecraft's instruments were operating normally. UARS is considered to be the first element of the international Mission to Planet Earth, the goal of which is to provide the data needed to construct comprehensive, accurate models of the Earth's physical, chemical and biological processes and the interaction among them.

Measurements made by UARS were confirmed and expanded by the Atmospheric Laboratory for Applications and Science (ATLAS-1) aboard the United States Shuttle Atlantis during a nine day mission (23 March through 2 April). The mission included a Japanese experiment using an electron beam to create an artificial aurora, instruments to measure the concentrations of ozone, atomic hydrogen, and trace gases, along with global water-vapour distribution in the upper atmosphere, and solar instruments to correlate these measurements with solar activity. ATLAS-1 experiments were monitored by weather stations around the globe, including 50,000 students at 1,000 United States schools equipped with radio receivers to detect the electron-beam phenomena. Five additional ATLAS flights are scheduled through 1997; five more may then be added to cover a full 11-year solar cycle.

In February NASA restructured the Earth Observing System (EOS), the primary element of Mission to Planet Earth, to consist of six medium-sized satellites instead of two large ones. Seventeen of the 30 instruments originally planned for the system will fly on the new fleet; six were deleted and seven deferred. NASA plans to fly three copies of each satellite, or a total of 18 during the life of the programme. All are compatible with the Atlas 2AS vehicle and some can be launched by Delta vehicles. In June NASA received five bids from competitors for the first two spacecraft of the restructured EOS, and subsequently granted study contracts to all five bidders. The ten instruments on EOS-PM 1 and EOS-Chemistry 1, scheduled to be launched in 2000 and 2002 respectively, will measure clouds, precipitation, solar radiation balance, ocean

surface winds, and the chemical composition of the atmosphere. Budgetary constraints have mandated a reduction in scope of the system and a common design for most of its spacecraft. In October NASA awarded a 10-year contract to develop and build the EOS Data and Information System (EOSDIS) to Hughes Aircraft Co. (United States).

On 11 and 27 February, Orbital Sciences Corporation (United States) signed up its first two commercial customers for ocean imagery to be collected by its Seastar satellite, expected to be launched aboard a Pegasus booster in August 1993. Satlantic (Halifax, Canada) and SeaSpace (San Diego, United States) joined NASA as customers for the colour images, which will be generated by Seastar's Sea-viewing Wide-field sensor (SeaWifs).

The 2,400-kg United States-France Topex-Poseidon satellite, launched into a 66-degree, 1320-kms circular orbit on 10 August by an Ariane 42P (No. 52), in October began its mission of mapping ocean currents and tides, measuring ocean levels, and determining atmospheric water-vapour content to support the development of global climate models. Both the 24-kg French Poseidon radar altimeter and the 220-kg NASA Topex altimeter were satisfactorily checked out in August and September. Topex-Poseidon has been termed the most important cooperative programme between the two nations' space agencies, NASA and CNES.

The same Ariane 42P that launched Topex-Poseidon also placed into orbit South Korea's first satellite, KITSAT-A, to be used for Earth imaging, amateur radio and relaying of educational programmes. It was designed and built by the University of Surrey (United Kingdom) and the South Korean Advanced Institute of Science and Technology.

Brazil signed an agreement on 14 July to launch its 115-kg remote sensing and data-relay Satellite de Coleta de Dados (SCD-1) aboard an Orbital Sciences Pegasus rocket at the end of 1992. From its 750-km orbit it will relay data on ground temperature and soil moisture from a number of ground-based data collection platforms, to be used in assessing the health of the country's rain forests. The satellite is the first in a series of four being planned by Brazil. Brazil plans to use a new indigenous launch vehicle for the last three. Brazil is Pegasus's first international customer.

On 24 July a Delta rocket launched the Geotail international spacecraft, a joint effort by Japan's ISAS and NASA. Part of the International Solar-Terrestrial Physics (ISTP) programme, the 970-kg spacecraft will study the tail of the Earth's geomagnetic field out to 220 Earth radii, focusing primarily on interactions of the field with the solar wind and solar flares. Also in July, India conducted a unique experiment to measure the vertical profiles of electron and ion densities and temperatures in the equatorial latitudes by correlating data from a Langmuir probe launched aboard a sounding rocket with simultaneous data collected by the Retarding Potential Analyzer on India's SROSS-C satellite and by the Mesosphere, Stratosphere, and Troposphere radar.

Sweden's 250-kg Freja satellite, carrying auroral imaging and magnetosphere-measurement instruments designed and built in Sweden, the United States, Canada, and Germany, was launched by China from its Gobi Desert site on 6 October as a "piggyback" payload (the main payload was China's 2,100-kg FSW-1 recoverable Earth-imaging satellite) aboard a Long March 2C vehicle.

C. Commercial Developments

In February Hughes Space and Communications Group (United States) purchased the largest single insurance policy ever issued for space ventures: over $800 million coverage for eight spacecraft and their launches.

In September India announced the formation of a commercial venture, Antrix Corporation Ltd., to market a wide variety of space products and services.

On 18 June an agreement was signed by Russia and Canada for Russia's first international commercial satellite system, to be launched by SovCan Star Satellite Communications Incorporated in 1995 and 1996. A Russian consortium led by Krasnoyarsk's NPO Prikladnoi Mekhaniki will provide the buses for the system's two satellites, the launch facilities, and the launches. A consortium of three Canadian companies will build and operate the payloads.

By year's end Orbital Sciences Corporation (United States), a relative newcomer to the commercial launch industry, had signed 86 contracts for 24 firm launches and 62 options totalling about U.S $1 billion.

IV. MANNED EARTH ORBITAL ACTIVITIES

Commonwealth of Independent States cosmonauts logged 18,658 hours in space in 1991; United States astronauts accumulated a total of 6,351 hours. Cosmonauts spent over 64 hours outside their Mir space station, while United States astronauts worked outside Shuttle orbiters for more than 21 hours. On 20 and 21 February 1992 Mir cosmonaut Sergei Krikalev broke his own world record, set in July 1991, when he conducted the seventh spacewalk by a single person. He returned to Earth on 25 March after a stay of over 10 months in the space station. Krikalev and his fellow cosmonaut Alexander Volkov, who returned with Krikalev on 25 March, were the first space travellers to return to a country, Kazakhstan, different from the one they were launched from, the Soviet Union.

Cosmonauts Alexander Viktorenko and Alexander Kaleri replaced two of Mir's five failed gyrodyne stabilizers during a two-hour spacewalk on 8 July, which was unique in that a half-hour of the work was conducted while Mir was in the Earth's

shadow. The two cosmonauts returned safely to Earth on 10 August, despite being trapped, with French cosmonaut Michel Tognini, for several minutes in the Soyuz TM-14 capsule which overturned on landing. Cosmonauts Anatoli Solovyov and Sergei Avdeyev, who were launched to Mir on 29 July, subsequently undertook four spacewalks totalling 18 hours in September to mount the Sofora package containing four thrusters on Kvant's 14-m mast, significantly improving Mir's attitude control.

The new Russian Space Agency announced in March that government-financed development of the Russian shuttle Buran and its Energiya launcher will be abandoned in order to continue operation of the Mir space station and expand its mission with the already-built Priroda module for environmental monitoring. (It was later announced that sufficient funding would be provided to keep the programme on a standby status.) Priroda is scheduled for launch in 1993 and a final element of Mir is likely to be launched to the station in 1994. Despite severe budget constraints, Russia still plans to launch the core of a new station, Mir-2, by 1998.

Astronauts aboard the United States Shuttle Discovery International Microgravity Laboratory-I mission from 22 to 30 January conducted extensive experiments on human balance-sensing organs, an analysis of back pains which plague both astronauts and people on Earth, the transformation of fluids into vapour, growing a variety of crystals (including protein crystals for modelling pharmaceuticals), and the effects of microgravity and radiation on various forms of living cells. The subsequent flight of the United States Microgravity Laboratory (USML-1) aboard Shuttle Columbia, launched 25 June, grew more than 30 protein crystals for use on Earth in conducting X-ray structure studies of an immune-system factor, a blood-clotting protein, and an AIDS virus protein, among others. The presence on board of trained crystallographer Lawrence DeLucas, along with the extended duration of the flight (14 days), produced better results than all previous crystal-growth attempts. Semiconductor crystals grown during the long USML-1 mission were also larger than any grown on previous Shuttle flights.

On 4 February, NASA reopened the opportunity for experimenters to attach instruments to the exterior of Space Station Freedom, an option which had been deleted during one of many previous redesigns of the station. Four attachment points will provide up to 3 kW each, along with data transmission connections. In August NASA initiated a reexamination of alternative launch systems that might supplement the Shuttle in deploying and servicing the station (see above). Budget constraints in the United States have forced a delay in launching the first elements of Freedom until March 1996. Crew-tended operations will not begin until June 1997 and full station occupancy will be achieved in June 2000.

One of the most exciting events of the year occurred when three astronauts aboard United States Shuttle Endeavor, on its maiden flight from 7 to 16 May, finally succeeded in capturing and relaunching the 4,000-kg Intelsat VI-F3 satellite, which had

been stranded in a useless low orbit by a miswired Titan-3 launch vehicle in March 1990. The satellite later reached its proper operating orbit, and was placed into service by mid-July in time to relay broadcasts of the summer Olympic games from Barcelona, Spain. The successful retrieval, made using last-minute tactics devised by the Endeavor crew after carefully rehearsed procedures had failed, demonstrated conclusively the need for in-space testing and demonstration to supplement ground simulations, no matter how detailed and thorough they may be. The new Shuttle orbiter is equipped with many new systems, including a 12-m drag parachute to decrease its landing run, making it possible to conduct more landings at the Kennedy Space Center launch site, and modifications to permit extended missions lasting up to 28 days.

On 18 June, NASA and the Russian Space Agency reached an agreement to study the use of the Soyuz capsule or its derivatives as Space Station Freedom's Assured Crew Return Vehicle (ACRV), development of an automated rendezvous and docking system based on the one Russia uses in operations with the Mir space station, and the possibility of NASA conducting life-science experiments aboard Mir. A subsequent agreement was finalized by the two agencies on 16 July, aimed mainly at joint human missions but covering many additional subject areas such as a broad programme of cooperation on global environment monitoring, possible purchase by the United States of a small Russian lander for the Mars 94 mission, support for Galileo data transmission using Russian deep-space antennas, joint life-sciences missions, and visit exchanges. A subsequent agreement reached in October set the first Shuttle flight of a Russian cosmonaut, either Vladimir Titov or Sergei Krikalev, aboard Discovery on Mission 60 in November 1993, and the first visit of a United States astronaut to Mir for a 90-day mission starting in January 1995. A United States Shuttle will then dock with Mir to return the astronaut and two cosmonauts to the United States, and will also carry the Russian replacement crew to Mir.

A variety of commercial agreements were entered into by United States and Russian firms. For example, on 27 August, NPO Energiya of Russia signed an agreement with Lockheed Missiles and Space Company to work together on the use of Soyuz-TM technology in an ACRV and other areas and on 4 September Rockwell International (United States) agreed with NPO Energiya to cooperate on a docking system for Mir and the Shuttle. In early October McDonnell Douglas (United States) signed an agreement with Russia's IMASH to coordinate research on advanced spacecraft engineering and materials. On 26 October Pratt & Whitney (United States) and Russia's NPO Energomash agreed to develop jointly hydrogen-fuelled rockets for heavy-lift launchers.

A much-anticipated test of the Italian-United States Tethered Satellite System, conducted during Shuttle Atlantis' 31 July-8 August flight, was not completed due to a snag which developed in the tether deploying mechanism. Despite several efforts to free the cable, the 1.5-m, 520-kg Italian satellite was only deployed 260-m from the Shuttle's payload bay instead of the planned 19 km, hence developing only 40 volts by interaction

of the electrically conducting tether with the Earth's magnetic field rather than the anticipated 5,000 volts. The problem was eventually traced to the jamming of the tether by a bolt which had been added after completion of ground testing in order to strengthen a part of the deployment reel. Nevertheless, the absence of any major instability in the tether, which had been considered a serious potential problem before the mission, represented a significant finding for future tether flight experiments. A reflight of the experiment is under consideration, but no decision has been made to date. Germany's Kayser-Threde later received a contract from the German Space Agency to develop a 50-km tether project called RAPUNZEL, which is to be used to change the course of a reentry capsule deployed from a Russian Photon spacecraft in late 1995.

Another Italian programme flew on Shuttle Columbia (22 October-1 November) when LAGEOS-2 was deployed. LAGEOS-2 is a 405-kg, 0.6-m Italian laser reflecting satellite to be used for measuring tectonic-plate movement and other geodetic data. It was placed in its final 52-degree, 5,900-km orbit by Italy's new Iris spinning upper stage rocket.

On 9 September the ESA Council accepted the proposed cancellation of the Hermes demonstrator X-2000 (an already curtailed version of the original manned vehicle development), which was to have flown just once in 2000. ESA's intent is to work with Russia on a joint piloted space shuttle in the late 1990s, with a decision to come after three years of work by ESA and Russian organizations to define the details of this and other cooperative enterprises. The free-flying laboratory associated with the Columbus programme was also cancelled this year, leaving the pressurized Space Station Freedom laboratory as the only remaining major element of the Columbus programme.

In 1992 a number of countries participated in the operations of the Commonwealth of Independent States Mir space station and in flights of the United States Shuttle. From 17 to 25 March German Air Force test pilot Claus-Dietrich Flade conducted a number of experiments on the Mir 92 mission studying space sickness and testing physical endurance, radiation protection, and vision and balance in microgravity. French cosmonaut Michel Tognini operated the French Antares mission, with experiments in biomedicine and fluid and materials science, aboard Mir from 27 July to 10 August. Four more French cosmonauts are scheduled to fly to Mir by the end of this decade. Discussions of cosmonaut flights are underway with Israel, Chile, and South Korea.

Participants in United States Shuttle flights included Roberta Bondar of Canada, who conducted life-science studies aboard the International Microgravity Laboratory-1 mission, 22-28 January; Belgian astronaut Dirk Frimaut, who worked with ATLAS-1 environmental measurement instruments on Shuttle Atlantis, 23 March-2 April; Canadian scientist Steven McLean, who helped evaluate a new Space Vision System for the Canadarm, slated for use on Space Station Freedom, aboard Shuttle Columbia 22, October-1 November; and Japanese scientist Mamoru Mohri, who helped operate several

experiments in the Japanese-sponsored Spacelab J-1 on Shuttle Endeavor, 12-22 September (the 50th Shuttle flight). Mohri explained the experiments "live" to Japanese schoolchildren during a special half-hour television broadcast from space. The 43 J-1 Spacelab experiments included one on the breeding and hatching of tadpoles in space and observing their behaviour compared with that of tadpoles bred on Earth and carried into space.

On 6 October four people began a two-month stay in simulated space-station modules at Cologne, Germany. Selected from ten candidates who underwent four months of astronaut-type training, the four will be evaluated by ESA for their ability to get along with each other in a small enclosure, to ascertain the effectiveness of the astronaut selection process. This test builds on a previous four week test run by ESA in Bergen, Norway in 1990.

V. SPACE EXPLORATION

A. Astronomy and Astrophysics

The two operational "Great Observatories" led by the United States Hubble Space Telescope and the Compton (Gamma-Ray) Observatory, continue to provide unprecedented scientific data, despite Hubble's optical-system flaw. An image made with Hubble's Faint Object Camera, an ESA instrument, provided the best image ever of an aurora on Jupiter, and details of galaxy M87, including the presence of a gigantic black hole at its center, that are unmatched by any previous telescope. A second black hole only 2.3 million light years away was also found in a small galaxy, M32, implying that black holes are common rather than rare astrophysical phenomena. Hubble also obtained the sharpest image ever of one of the universe's hottest stars, in the nebula NGC-2440, and identified a stream of protons at the onset of a solar flare from a small red star as a mechanism which might help explain the cause of solar flares on the Sun. Presentations on Hubble's results dominated the American Astronomical Society's 179th Annual Meeting, 12-16 January. The Corrective Optics Telescope Axial Replacement (Costar) scheduled for early 1994 is expected to restore Hubble's capability to over 80% of that originally planned.

The Compton Gamma Ray Observatory captured the first image of the Sun in neutrons, marking the first time an astronomical image had been created by transmission of matter rather than electromagnetic radiation. Neutrons generated by nuclear processes on the Sun during a large solar flare on 15 June were detected by the COMPTEL instrument aboard the Compton Observatory. An unexpected "gamma ray afterglow," also detected after the 15 June flare, suggests that the Sun's corona stores protons in much the same way they are stored in the Earth's Van Allen belts. Compton also discovered on 8 August the brightest gamma-ray source in the sky, suspected to be an X-ray nova, in the constellation Perseus. India's Gamma Ray Burst experiment

aboard the SROSS-C satellite launched on 20 May (see above) provided additional data on gamma-ray bursts and their sources.

In April NASA's Cosmic Background Explorer (COBE), launched in 1989, observed an unevenness in the intergalactic microwave background that may be the residue of anomalies which created the galaxies, as predicted by the "Big Bang" theory. COBE's finding has sparked a whole new wave of theories on the processes by which the universe evolved from the initial moment of creation.

Due to budget constraints NASA decided in May to divide the big (15,000-kg) Advanced X-ray Astrophysics Facility (AXAF) into two separate spacecraft. One of these would be a 5,000-kg platform, to be launched by a Shuttle as early as 1998; it would carry imaging cameras. The other, a smaller spacecraft to be launched on a Delta booster, would be equipped with an X-ray spectrometer.

The 3300-kg United States Extreme Ultraviolet Explorer (EUVE), launched by a Delta-2 rocket into a 550-km orbit on 4 June, has begun detailed studies of nearby stellar objects in the spectral range between ultraviolet and X-rays. It will first conduct a six-month sky survey using its three scanning telescopes, a deep-survey telescope, and a spectrometer, after which it will study individual sources selected by over 200 guest astronomers.

ESA's Hipparcos satellite, launched in August 1989, also continues to catalogue stellar positions, parallaxes, star photometry, and double-star parameters, superseding in both quantity and quality all previously available data. The spacecraft is capable of operating approximately until mid-1994. ESA's Infrared Satellite Observatory (ISO) is planned for launch aboard an Ariane rocket in 1994. Four new missions are being considered by the Agency for its XMM observatory, to be launched in 1998: Marsnet (part of the Mars Environmental Survey [MESUR]), STEP (to verify the equivalence principle), Integral (a large gamma-ray observatory being planned jointly with NASA), and Prisma (a stellar observatory). One of these missions will be selected for implementation in mid-1993.

The Russian Gamma-1 operated until the end of February, when its instrument's power supply failed. It observed pulsars and detected very high-energy solar flares (>1 GeV) for the first time. The Russian Granat spacecraft, launched in December 1989, will continue to operate until June 1993. Its French Sigma telescope has identified hard X-ray and soft gamma-ray sources and located them with high accuracy.

B. Space Plasma Physics

Planning and spacecraft construction continued this year for the Solar Terrestrial Science Program, supported by NASA, ESA, and ISAS. The programme includes the

following: NASA's Global Geospace Science (GGS) effort, whose objectives are to determine the mass, impulse, and energy exchanges in the Earth and near-interplanetary environment, to measure the effects on the Earth's environment of energy-supply variations in the atmosphere, and to model the global system; ESA's Cluster mission, designed to study the structure of the terrestrial magnetosphere and associated turbulence; and ESA's Solar and Heliospheric Observatory (SOHO), which will study the Sun's interior and the origins of the solar corona and solar wind. GGS spacecraft launches are scheduled for 1993 and 1994. Cluster will be lofted by an Ariane-5 in 1995; and SOHO by an Atlas 2AS in 1995.

Meanwhile in June the Japanese spacecraft Yohkoh completed a series of X-ray images of the Sun's corona taken at sufficiently high frequency to construct a cinematographic study. These images, taken by the spacecraft over a nine month period following its launch on 30 August 1991, were the first X-ray images of the Sun since the United States Skylab mission in 1973.

The first in a new series of low-cost NASA Small Explorer missions was launched by a Scout rocket from Vandenburg Air Force Base on 19 June. The 158-kg Solar, Anomalous, and Magnetic Particle Explorer (SAMPEX) spacecraft, a joint effort by Germany and the United States was placed in a 550 x 675 km polar orbit. One of its missions is to collect data on mysterious high-energy particles that may come directly from interstellar sources.

The Commonwealth of Independent States expects to launch its four-satellite Interball mission in 1993. By employing two satellites in polar orbit and two in highly eccentric orbits, Interball will enable simultaneous, coordinated measurements of plasmas in the far magnetosphere, in the interplanetary environment, and in the polar cusps created by interaction of solar plasma with the ionosphere.

C. Solar System Exploration

The Galileo spacecraft is now approaching Earth for its second gravity assist from our planet, after which it will continue its long voyage to explore Jupiter and its moons. Galileo's 4.8-m antenna continues to defy efforts to free its jammed mechanism (since May 20, 1991, ten heating-cooling cycles performed by turning the spacecraft have been unsuccessful), so Jet Propulsion Laboratory (JPL) engineers have devised a plan to enhance by a factor of 100 the data transmission capability of the functioning low-gain antenna. Techniques planned include data compression, new error-correction coding algorithms, increasing Earth-antenna sensitivity, and using arrays of Earth antennas. The Commonwealth of Independent States has offered to modify its big 70-m deep space antennas at Ussuriysk, Russia and Yevpatoriya, Ukraine for Galileo data reception in the event the spacecraft's antenna cannot be freed, to supplement existing NASA antennas in Spain and Australia. Photographs of the 19 x 12 x 11 km asteroid Gaspra taken by

Galileo last October were transmitted to Earth in June, when Galileo came near enough to transmit sharp images through its low-gain antenna. The new photos show over 600 meteorite impacts, some as big as 100-m in diameter.

The Ulysses Sun-explorer spacecraft swung by Jupiter during 17 days in February, making its closest approach (376,000 km) on 8 February. Ulysses used the giant planet's gravity to enter a heliocentric polar orbit which will bring it over the Sun's south pole from June to October 1994 and over its north pole from June to September 1995. During its flyby of Jupiter, the spacecraft's instruments revealed that Io's volcanic activity had decreased significantly since Voyager had photographed the moon in 1979, that Jupiter's magnetosphere had expanded substantially since Voyager, that ions emitted from Io created a giant plasma torus around Jupiter, and that the solar wind compresses Jupiter's magnetosphere at the poles much like Earth's. None of Ulysses' nine instruments were damaged by the intense magnetic field or by the heavy exposure to charged particles.

Magellan's mapping of Venus by radar was interrupted on 4 January by failure of its main science data transmitter and a whistle on the backup transmitter, but the backup transmitter was successfully reactivated on 24 January. A 22 April briefing of radar survey results noted the identification of over 1,500 volcanic features, randomly spread over the planet and spawning about one major landslide annually. The transmitter was shut down again in July due to radio noise interference, but was started up again and on 13 September Magellan completed its radar mapping session, which raised the total coverage of Venus to 99 per cent, far exceeding the 70 per cent programme goal. Meanwhile the 370-kg Pioneer Venus (United States) entered Venus's atmosphere and burned up on 8 October, after having transmitted thousands of photos during its more than 5,000 orbits of the planet since its launch on 20 May 1978.

On 14 September Magellan's periapsis was lowered from 258 to 184 km to facilitate the spacecraft's final measurement cycle, a gravimetric study of Venus. The apoapsis of the spacecraft's elliptic orbit remains at 8,540 km, reducing gravimetric resolution at the poles to worse than 1,000 km. Hence JPL is considering extending the gravimetric mapping cycle, which is currently scheduled to end in May 1993, by using a series of aerobraking manoeuvres to achieve a circular orbit that would provide full-planet gravimetry resolution to nearly 200 km. The final decision on this manoeuvre, which would also test the as-yet conceptual aerobraking methodology for the first time, will be guided by budgetary considerations.

ESA's 1,000-kg Giotto comet explorer, reactivated in July 1991 after its spectacularly successful flyby of Halley's Comet in March 1986, passed within about 200 km of the nucleus of comet Grigg-Skjellerup on 10 July. Eight of Giotto's original complement of eleven experiments were successfully operated during the flyby. Also, Japan's Sakigaki spacecraft, another member of the Halley armada, was brought back to within 90,000 km of Earth on 8 January to study the interaction between the solar wind and the Earth's magnetic field.

The United States president's budget issued 29 January deleted NASA's Comet Rendezvous Asteroid Flyby (CRAF) mission due to budget constraints, but the NASA/ESA Cassini mission to Saturn is still planned for a 1997 launch. In examining potential avenues for reducing programme costs, JPL eliminated the two long booms and platforms that were to allow cameras and other instruments to rotate, reducing the total data return potential of the spacecraft. However, no instruments were deleted, and the reduced spacecraft mass now allows the use of a standard Titan-4 launcher without upgraded boosters, whose development has experienced recent problems. Overall cost reduction is estimated at about 15 per cent.

At the World Space Congress in September, NASA announced a proposal to fly two 150-kg probes on a direct trajectory to Pluto, the solar system's outermost planet and the only one not yet visited by a spacecraft from Earth. Aimed at studying the planet before its atmosphere condenses as it moves away from its closest approach to the Sun in 250 years, the Pluto Fast Fly-By mission to study Pluto and its moon Charon could be launched by a Titan-Centaur as soon as 1998 and reach Pluto about 7 years later.

Motivated by the potential hazard associated with a major asteroid impact with Earth, such as is believed to have contributed to the extinction of the dinosaurs and many other terrestrial species about 60 million years ago, NASA organized two workshops. One in June 1991 aimed at improving the detection rate of Earth-approaching asteroids and comets and the second, in January 1992, discussed possible means for deflecting or destroying any large object that may be found to be on a collision course with Earth. Studies of collision implications are also underway by the International Astronomical Union and by the Commonwealth of Independent States.

The spotlight in solar system exploration is now focused on Mars. NASA'S 2600-kg Mars Observer was launched 25 September on a Titan-3 using the first Transfer Orbit Stage (TOS) delivered by Orbital Sciences Corporation. After its 11-month voyage, the spacecraft will enter a 390-km Mars polar orbit and for a Martian year (687 Earth days) its seven instruments will map the planet's topography, magnetism, minerals, winds, and moisture, if any. Its narrow-angle camera, with a resolution of about 3 m, will produce the most detailed pictures ever taken of Mars. The spacecraft also carries a French radio to relay transmissions from the Russian Mars 94 lander and penetrators (see below) and, if still active in 1997, from the Russian Mars 96 rover and balloon.

NASA's future efforts in exploring Mars will employ small spacecraft. The Mars Environmental Survey (MESUR), which NASA will seek to start in 1996, features four Delta-rocket launches from January 1999 to December 2003, each carrying four Mars landers. The 16 small stations would form a global network to study Mars' meteorology, seismic activity, and local surface conditions. NASA also plans a MESUR Pathfinder, to be launched in 1996, as part of its small-spacecraft Discovery programme. It would

demonstrate the technologies required for MESUR, including a small rover able to haul a 3-kg instrument package and a camera.

The Russian Mars 94-96 mission continues under the jurisdiction of Russia's new space agency, RKA. France and Germany have agreed to contribute financial support as well as technical aid, experiments, and equipment. In October 1994 a Mars orbiter, two small surface stations, and two penetrators will be launched. The 1996 launch will consist of a Mars orbiter and a descent module containing a balloon and a small rover. Balloon and guiderope tests were performed by the French space agency CNES this year, and in May the Russian rover was tested on typical Mars terrains in California's Mojave Desert, providing the first demonstration of autonomous surface navigation by a prototype vehicle.

Japan's ISAS will in July-August 1996 launch its 450-kg Planet-B Mars research spacecraft aboard an M-5 launcher. The spacecraft's ten instruments will study the interaction of the solar wind with Mars' upper atmosphere. ESA's Marsnet, a network of three landers to be launched in 2001 in conjunction with MESUR, is one of the four projects competing for ESA's MMX approval in 1993.

D. Search for Extraterrestrial Intelligence (SETI)

SETI activities in the United States expanded significantly this year. NASA's High-Resolution Microwave Survey (HRMS), which is the new name for the United States SETI programme, began on 12 October with an initial 10-MHz Targeted Search using the Arecibo (Puerto Rico) 305-m antenna, and a Sky Survey using a 20-MHz, 2-million-channel system with the new 34-m beam-waveguide antenna at the Goldstone Deep Space Network station. The Targeted Search will expand to 20 Mhz, and will examine 1,000 stars out to a distance of 100 light-years for signals in the 1-3 GHz range that may drift in frequency by as much as one part in a billion. The Sky Survey will eventually process 320 MHz into 16 million channels for two polarizations in the 1-10 GHz range. The systems will reach full capability in 1995, and observations will continue until 2001.

Other developments in the United States this year included upgrades at the Ohio State University Radio Observatory, operation of the new 4-million-channel Serendip-3 system at 430 MHz at Arecibo, initiation of a new infrared search of nearby Sun-type stars for carbon-dioxide laser emission at Mt. Wilson Observatory, and continuation of the northern-hemisphere sky search by Harvard University's META-1 project. Its southern-hemisphere counterpart in Argentina, META-2, completed a survey at the 1420-MHz hydrogen-line frequency, and conducted simultaneous observations, with META-1, of those portions of the sky visible to both. The META systems will be upgraded, first to 100 million and eventually to one billion channels. A related low-cost NASA programme concept, "Toward Other Planetary Systems" (TOPS), would use

existing space systems in combination with ground-based observatories such as the Keck-II telescope to search for, identify, and examine planets around other stars.

The 64-m Parkes Observatory antenna and the MOPRA 22-m antenna in Australia are being tested and upgraded for use in the NASA HRMS Targeted Search. Future upgrades for that purpose are planned at the 34-m Deep Space Network antenna near Canberra and the Nancay Observatory in France.

The University of Bologna in Italy plans a sky survey near 400 MHz with a new spectrometer being built for their Northern Cross telescope. A Giant Meterwave Radio Telescope consisting of a thirty-telescope array of 45-m antennas near Pune, India, is being built to cover frequency bands up to 1420 MHz. A new 70-m antenna in Uzbekistan capable of SETI surveys is being added to the Commonwealth of Independent States Deep Space Network, and SETI observations are also planned for the large Armenian millimetre-wave telescope at 203 GHz.

VI. TECHNOLOGY ADVANCEMENT

A. Propulsion

A formerly secret United States nuclear rocket research programme was made public on 13 January. Originally conceived as a potential upper stage powerplant for strategic defense missiles, the Space Nuclear Thermal Propulsion (SNTP) concept utilizes a particle-bed reactor, a scheme first publicized by a research effort at the Brookhaven National Laboratory beginning in the 1960s, to generate higher thrust/weight ratios than the "conventional" solid-core nuclear rockets which were developed during the United States NERVA programme in the 1960s. The SNTP programme is continuing under the sponsorship of the United States Defense Department at a 1992 funding level of about $65 million, but budgetary support in 1993 is doubtful and future funding has yet to be committed. It is of interest as a potential alternative to the NERVA-derived technology now being explored by NASA for possible use on future Mars expeditions.

Three successful test firings of the American Rocket Company's 1,000-kN H-500 hybrid rocket engine were conducted on 21 and 24 January and on 11 February. An industry-funded consortium led by Thiokol and composed of United Technology's Chemical Systems Division, General Dynamics, and Martin Marietta was created in March and April to work with NASA's Marshall Space Flight Center in the development of alternate hybrid rocket designs. Testing at Thiokol started in May on motors at the 13 kN level, which will be upped to 180 kN by the end of the year. Thiokol also tested a new 530 kN solid-propellant booster rocket, the Castor 120, on 22 April. The low-cost graphite-epoxy motor will be available commercially late next year; it is already slated for use on Orbital Science Corporation's Taurus vehicle.

The United States Solid Rocket Motor Upgrade (SRMU) for the Titan 4 launch vehicle, which develops 7,500 kN thrust and increases the vehicle's payload capacity by 25 per cent, underwent its first successful full-scale firing on 12 June and its second on 15 October. The previous test, in April 1991, had ended in an explosion. The three-segment graphite-epoxy motor, slated for three more test firings before going into service in late 1993, increases Titan-4's low Earth orbit payload capability from 17,700 to 21,700 kg.

In January Russia reported that a supersonic-combustion ramjet (scramjet) engine had been test flown at Baikonur, Kazakhstan on 28 November 1991 by Moscow's Central Institute of Aviation Motors (CIAM), following two preliminary flights during which the engine was not ignited. In the 28 November test the gaseous-hydrogen-fuelled engine first operated as a ramjet, accelerating the test vehicle from Mach 3.5 and converting from ramjet to scramjet propulsion at Mach 5.6 (over 7,000 km/hr) at an altitude of about 28 km. Maximum speed attained was about Mach 6. A subsequent test this year achieved a speed in the Mach 7 to Mach 8 range. The scramjet is the key technology driver for airbreathing single-stage-to-orbit launchers currently being explored in the United States National Aerospace Plane programme as well as in several other countries. CIAM has invited the United States to cooperate in scramjet development.

Russia's NPO Energomash in April unveiled the RD-701, a new dual-fuel rocket engine. Also called a "tripropellant engine," it uses liquid oxygen with a hydrocarbon fuel for its boost phase, during which it develops 1,800 kN thrust, and subsequently with liquid hydrogen produces 720 kN (vacuum) thrust. The United States explored the dual-fuel concept analytically in the 1960s and 1970s, but never built an engine. The RD-701 is planned to power a single-stage-to orbit vehicle weighing about 22 tonnes, which will be launched with its 200-tonne propellant tank from an An-225 cargo aircraft. Russia's Trud/Samara State Scientific and Production Enterprise this year offered to sell 94 engines built originally for the Soviet N-1 Moon rocket in the 1960s. The oxygen/kerosene first-stage NK-33 engines (of which 62 are available) develop a sea-level thrust of 1500 kN at 331 seconds specific impulse. Twelve NK-43 second-stage engines (1750 kN vacuum thrust), 10 NK-39 third-stage engines (400 kN vacuum thrust), and 10 NK-31 fourth-stage N-1 engines are also available.

Japan has developed a new bipropellant Liquid Apogee Propulsion System (LAPS). Using hydrazine and nitrogen tetroxide, it can transfer a 2-tonne-class satellite (e.g., Engineering Test Satellite 6) from a geosynchronous transfer orbit to the geostationary orbit. The xenon ion-propulsion thruster to be flight-demonstrated aboard ETS-6 has completed 60 per cent of its 50,000-hr lifetime test.

Two tests of the H-2's first-stage LE-7 hydrogen/oxygen engine were terminated prematurely on 16 and 20 April, but were followed by two full-term (365-second) tests on 5 and 10 June. Unfortunately, however, a subsequent fire that started 5 seconds into an 18 June LE-7 test will delay H-2's first launch until early 1994.

In November Japan's Mitsubishi Heavy Industries used a liquid-hydrogen-cooled heat exchanger to liquefy air, which was then burned with hydrogen in a 100-kN L-5 rocket engine (the second-stage engine of the H-2). Mitsubishi plans to test-fly in 1997 a more complex liquid-air cycle engine (LACE) concept, said to be able to reach liquefaction ratios (air to hydrogen) of 14 as compared with the value of three reached in the November ground-test.

Europe conducted its first space test of an ion thruster, MBB's Radiofrequency Ion Thruster Assembly (RITA), aboard the Eureca spacecraft on 12 August. The test lasted for 10 hours at 380 W. A total of 1700 hours of testing is planned. RITA will be used in conjunction with the UK's Electron Bombardment Ion Thruster Assembly (EITA) for stationkeeping of Europe's Advanced Relay and Technology Mission (ARTEMIS) during a 10-year demonstration flight scheduled to begin in 1995.

Late in the year the Lawrence Livermore National Laboratory in the United States used a two-stage light gas gun to launch a 5-kg projectile to a speed of 4 km/sec. Engineers working on the Super High Altitude Research Project are considering replacing the methane/air-pumped hydrogen gun by one which uses advanced electric-arc or particle-bed hydrogen-propellant heaters to orbit payloads with masses of several tonnes.

B. Power

ESA's Eureca satellite, deployed from United States Shuttle Atlantis on 1 August, uses a 5 kW solar array built by Fokker Space and Systems (Netherlands) which not only opens, as on many previous spacecraft, but also can be refolded for return to Earth by the Shuttle when Eureca completes its mission. The array is also designed to be reused five times, another "first" for large solar arrays.

Early this year Russia sold and delivered two unfuelled Topaz-2 nuclear space power reactors to the United States for test and evaluation. The Topaz-2 is a thermionic power system using multiple-cell fuel elements (in contrast to the single-cell elements used in Topaz-1, which flew several times aboard then-Soviet Radar Ocean Reconnaissance Satellites (RORSATs). Topaz-2, which has never been flown in space, will be used by the United States Strategic Defense Initiative Organization (SDIO) to develop thermionic reactor technology for a space power system able to upgrade Topaz-2's power, about 5 - 10 kWe, to the 40 kWe range. SDIO has also purchased two additional reactors, which it plans to flight test in December 1995. The spacecraft for the test flight, which will evaluate not only the reactor but also a high-power xenon ion propulsion system in a nuclear-safe orbit (1,000 km), is being developed by the Applied Physics Laboratory at Johns Hopkins University. Technical support, including exhaustive consideration of nuclear safety, is being provided to SDIO by Los Alamos National Laboratory, Sandia National Laboratory and the University of New Mexico.

SDIO expects to select a commercial launch vehicle for the flight test late in 1992 or early 1993. Testing of the unfuelled reactors has been undertaken at Sandia with the help of about 20 Russian engineers and technicians, using test equipment also purchased from Russia.

C. Automation, Robotics, and Teleoperators

In Death Valley, California during the period 24-27 May, Marsokhod, a six-wheeled prototype Russian rover, was successfully tested in combination with two United States minirobots designed to be carried by Marsokhod during the Russian Mars 96 mission. The minirobots, named Attila-2 and Pebbles, were built by ISX Corporation and IS Robotics Corporation. Attila-2, a six-legged robot, was designed at the Massachusetts Institute of Technology. Pebbles uses a segmented-track drive, similar to that of a tank. Sixteen Mars rover designs were displayed at the World Space Congress, held in Washington from 28 August to 5 September. They ranged in size from JPL's 30-cm Rocky 3 to Carnegie Mellon's 5-m Ambler. One of the smaller devices was the Sandia Laboratory's 30-cm working model of a 4-wheeled All-Terrain Lunar Exploration Rover whose split-chassis design allows it to navigate large boulders and deep depressions. Sandia also defined a number of terrestrial applications for the robot in mining, penetrating into contaminated areas, and fire-fighting. In a demonstration planned for November, two robots designed and built by the Robotics Institute of Carnegie Mellon University in the United States will climb into the active volcano Erebus in Antarctica to take samples and photos of the lava lake's floor.

D. Environmental Effects of Spaceflight

1. Space Debris

The problems associated with space debris are having an increasing impact on space activities. For example, for the first time two United States Space Shuttle orbiters manoeuvred to increase their miss distance from spent rocket stages (Discovery, on Shuttle flight 48 and Atlantis, on Shuttle flight 44). Also, two explosions in the geostationary orbit occurred in 1992. One was an upper stage which deployed several satellites in 1968; it created about 20 fragments. The other was caused by the rupture of a nickel-hydrogen battery casing.

Fragmentation in the heavily used geostationary orbit is of particular concern because there is no removal mechanism comparable to the atmospheric drag present in low Earth orbits. As a result, NASA, ESA, and Intelsat have begun boosting their geostationary-orbit spacecraft into "graveyard" orbits about 300 km above the geostationary orbit. Motorola, the developer of the new low-orbit Iridium communication satellite system (see above) took the unprecedented step of voluntarily

agreeing to deorbit its 66 satellites when their useful life is over and allow them to burn up in the Earth's atmosphere. However, the propellant mass needed to boost or deorbit a satellite, which could exceed 10 kg for the heavier commercial satellites, would otherwise allow months of continued profitable operation, which generally deters commercial spacecraft operators from moving their satellites on a voluntary basis. The growing problems associated with space debris prompted the International Academy of Astronautics to call for a global organization to manage the reduction of space debris hazards.

On 10 January the United States tested the effect of an impact by a 150-gram pellet travelling at 6 km/sec, simulating a 5-10 cm piece of space debris, on an actual satellite (Oscar 22, a 55-kg obsolete Transit satellite). The impact generated a surprisingly large number of small, micron-sized particles, estimated to be about 30 million in number, and illustrated the potential hazards of collisions between space debris and spacecraft.

2. Atmospheric Effects

A study of United States, Commonwealth of Independent States and European launch vehicle effects conducted by the American Institute of Aeronautics and Astronautics (AIAA) in 1991 concluded that although the current impacts of rocket launchers on the ozone layer, global warming, acid rain, and local toxicity were minuscule relative to other anthropogenic effects, future regulations will require them to be reduced to the maximum practical extent. It was suggested that the IAF in 1992 recommend an international approach to address this issue. The United States Department of Transportation's Office of Commercial Space Transportation on 5 June released a study of the environmental impact of reentry vehicles, which concluded that such effects were negligible.

E. Microgravity Research

On 19 March the Canadian Research Agency conducted 5 materials processing experiments aboard a Canadian Space Agency rocket (CSAR-1), launched aboard a Bristol Aerospace Black Brant-9 sounding rocket from White Sands, New Mexico. The 480-kg payload included crystal-growth studies and experiments to measure the degradation of plastics and polymers in atomic oxygen.

A 5-kg experiment package designed and built by Payload Systems Incorporated (United States) was launched to the Mir space station aboard a progress M-11 capsule on 25 January, and returned to Earth by Mir cosmonauts Alexander Volkov and Sergei Krikalev on 25 March. The package contained 96 separate experiments on protein crystal growth for investigators in the United States Canada, Europe, and Japan. A previous

package had been sent to Mir in December 1989 and another is scheduled for launch at the end of 1992.

F. Space Research Facilities

In March Japan initiated development of its Space Flyer Unit, a 3,200-kg reusable platform slated for use as a laboratory for scientific research as well as for space engineering and industrial space processing experiments. To be launched by NASDA's H-2 and retrieved by the United States Space Shuttle, the platform's development is being directed by the Institute for Space and Astronautical Sciences (ISAS) on behalf of its cosponsors, NASDA and the Ministry of International Trade and Industry (MITI).

The 4,100-tonne European Retrievable Carrier (Eureca) was released from Space Shuttle Atlantis by Swiss astronaut Claude Nicollier on 2 August. After some difficulty with its deployment due to improper programming of its sensors, Eureca reached its 508-km circular orbit on 7 August and its 15 payloads were activated three days later. All experiments on board currently appear to be operating well. They include a wide range of studies, including microgravity research and astronomical observations. Eureca is the largest and heaviest European spacecraft ever built. It can carry 1,000 kg of payload in its 8.5 cubic-meter bay, maintain temperatures in the range 0-40 degrees C, provide 1-degree pointing accuracy, and transmit data to the ground at 256 kB/second.

The Ball Corporation (United States) in June announced the availability of a small, 70-kg spacecraft called Quickstar. The spacecraft can carry a 23-kg payload with 3-axis stabilization, has pointing accuracy to 0.1 degree at slew rates up to 10 degrees per second, provides 40W average power (80W peak), and transmits data to the ground at 1 MB/second. Launched as a secondary payload on a Delta rocket or similar booster, it is claimed to be able to fly a payload for up to 24 months from mission inception.

At the World Space Congress Lockheed Missiles and Space Company (United States) also unveiled a new low-cost graphite-epoxy spacecraft based on its forthcoming production of Iridium buses, complementing the F-Sat announced last year. The new spacecraft offers 1 kWe to customers who wish to fly payloads up to 450 kg aboard the 225-kg bus.

VII. EDUCATION

A. Teaching Programmes

In the United States, the SETI Institute is preparing supplementary science curricula for grades 3-9, to take advantage of strong student interest in extraterrestrial life. The guides will be translated into the language of any country whose schools agree

to use them. The United States Space Foundation offered its course for kindergarten through 12th-grade teachers, "Getting Comfortable Teaching with Space," six times in 1992, and also provides a Space Network on-line computer system to get space information and K-12 lesson plans to teachers. The National Science Foundation's "Project First Step," a six week middle-school science curriculum employing videodiscs, uses aerospace examples to show the connections among the various sciences. The American Astronautical Association helped sponsor *USA Today's* "Visions Program" in 29 regional classrooms.

Over 200,000 students have flown simulated missions at The Challenger Center for Space Science Education's thirteen Challenger Learning Centers. The Center also organized the construction by students, teachers, astronauts, and cosmonauts of "Marsville: The Cosmic Village" during the World Space Congress. The Planetary Society created an educational programme, "Marslink," to enhance classroom activities through the use of Mars Observer data. The Young Astronaut Council spearheaded development of a curriculum package, "Exploration and Discovery," which went to every United States elementary, middle, and junior high school in January. Approximately 2,000 posters were submitted in a Space Art Contest for NASA's official ISY poster, sponsored by NASA and the Young Astronauts. The AIAA sponsored the NASA/National Science Teachers Association Space Science Student Involvement Program, and organized for NASA an October workshop to identify and develop avenues for motivating and enhancing science and engineering education in grades K-12.

The Satellite Educators Association helped spearhead a drive to introduce the use of remote-sensing imagery into classrooms across the United States to help teach science, math, physics, economics, and environmental studies. Previews of educational packages that link satellites to the classroom were previewed at the 18-20 March Satellites and Education Conference in Pennsylvania. Some 1,200 schools in the United States are already equipped to receive data from both polar and geostationary-orbit satellites operated by the United States National Oceanic and Atmospheric Administration (NOAA). A similar programme in Germany, sponsored by Bonn University and a Bonn company called Geospace, involves 150 high schools in an ISY programme to study urban growth using satellite imagery.

Engineering students at the Mississippi State University at Starkville (United States) constructed a 15-m, 2,300-kg mockup of the United States National Aerospace Plane with support of the Air Force-NASA joint programme office. It was exhibited at the Experimental Aircraft Association's Fly-In at Oshkosh from 31 July to 6 August and at the World Space Congress.

On 18 September an Orion sounding rocket carried a 60-kg ozone-measuring experiment designed and built by students from six Colorado (United States) universities to an altitude of about 60 km. The Colorado Student Ozone and Atmospheric Rocket,

sponsored by the Colorado Space Grant Consortium, was launched from the Wallops Flight Facility in Virginia.

In 1992 the British Interplanetary Society prepared student and teacher booklets, supported by a wide range of videos, on space-related subjects, emphasizing the history of astronautics and topics listed in the UK National Curriculum. The British National Space Centre conducted an Earthwatch competition in which student-teacher teams from 250 schools used Landsat images to define and solve environmental problems, and the UK's National Remote Sensing Centre in April began to distribute a curriculum package called "Pictures and Pixels" to United Kingdom schools to help students understand geographic scale and perspective through the use of satellite images. The Canadian Aeronautics and Space Institute held a Space Education Workshop in Ottawa on 4 November, concurrently with the Canadian Students Space Conference.

The ISY international Discovery of Earth Observation and Image Processing conference, held in Hennebont, France, demonstrated to 30 educators from seven nations the basics of remote sensing at the high-school level using kites and simple cameras. The programme was supported by the French Ministry of Research and Space and by the United Nations Office for Outer Space Affair. At Mourmelon, France, on 25-26 July the ISY Worldwide Launching Campaign for Student Rocket Experimental Payloads was the site for the launching of 15 experimental rockets by students from 12 countries. An international educators' seminar was also offered.

Facilities at the Moscow Aviation Institute and in Kaliningrad were opened for international educational activities in space subject areas. These included continuing education, student conferences, a conference on Space in the 21st Century, a summer aerospace school, an international space camp, and visits by teachers and schoolchildren from other nations.

The first Australian international space school, patterned after the successful programme in the United Kingdom to develop and distribute resources on the space theme in primary and secondary-school grades, was held from 19 to 23 July in Sydney, with 80 students from six nations.

In February Japan announced plans to use its Engineering Test Satellite (ETS)-5 for educational programmes, following the lead of the United States Peacesat programme operated by the University of Hawaii with the GOES-3 satellite. Users for the Japanese project, called the Pan-Pacific Regional Telecommunications Network Research Satellite (PARTNERS), are expected to include rural areas of Thailand, Indonesia, New Guinea, and possibly South Korea.

Technion's Institute for Space Research in Israel initiated a two-year programme in which students will design, develop, build, launch, and operate a series of small satellites. The first of these, a 60-kg spacecraft called Techsat 1, will be launched into

an 1120-km polar orbit in 1994. Roughly 280 Technion students, at a rate of 35 per semester, will develop the satellite's instruments with the help of 12 sponsoring Israeli corporations.

Computer software aimed at worldwide training in space oceanography was developed by the United Nations Education, Scientific and Cultural Organization's (UNESCO) Training and Education in Marine Science Programme. Twenty lessons were distributed at no cost to over 350 recipients in 70 countries.

The International Space University held its fifth summer session in Kitakyushu, Japan, with 127 students representing 29 nations. Three finalists in the competition for the ISU's permanent campus site were announced at the World Space Congress: Strasbourg, France; Kitakyushu, Japan; and Toronto, Canada. The final selection will be made early in 1993.

B. Public Awareness

The International Space Year (ISY) was formally inaugurated during separate January ceremonies in Paris, Washington, DC, and Tokyo. The first ISY mission was the International Microgravity Laboratory flight described earlier, in which Europe's Spacelab was carried to orbit aboard the United States Shuttle Discovery.

The IAF Education Committee held the Second International Seminar on the Future of Space Education in Alma-Ata, Kazakhstan 27-30 May, focusing on the education of both space workers and the general public. The third seminar will be held in Germany in May 1993; the fourth is planned for China in 1994. The United States ISY Association sponsored an ISY Global Change Education Conference for representatives of 90 major civic, education, environmental, and religious organizations.

The H. Dudley Wright International Student Contest was organized by the Planetary Society on the theme "Together to Mars," to focus young people's interest on planetary exploration. High-school students from 33 countries submitted essays on the subject, and the 20 winners and their mentors received an all-expense-paid trip to the World Space Congress. The Association of Space Explorers' Eighth Planetary Congress in Washington, DC from 23 to 30 August featured public lectures and sessions on the "Together to Mars" theme and a space art exhibit in the World Bank Art Gallery. The United States National Space Society circulated its "Grand Tour of the Solar System" to 20,000 school libraries, and continued its active promotion of public awareness and support for space. Spaceweek 1992 in the United States featured public lectures, library and museum exhibits, and educational demonstrations in support of space activities. The World Space Congress featured two student and three education sessions and opened its exhibit hall to the general public at no cost.

The IBM Gallery of Science and Art in New York mounted a space exhibit from 14 January through 28 March. Organized by the United States Space and Rocket Center in Huntsville, Alabama, the "Blueprint for Space: Science Fiction to Science Fact" exhibit featured over 175 artifacts dating from the early 17th century. A June exhibit at the new German Art and Exhibit Hall in Bonn combined remote-sensing data, computer graphics, and video animation to present visitors with three-dimensional simulations of global changes.

The French space agency CNES, the rocket-engine company SEP, and the French Palace of Discovery sponsored an exhibit of 16 posters on the basics of space operations at the Chicago Museum of Science and Technology and other locations. More than 920,000 copies of the accompanying 32-page booklet were distributed to passengers on all Air France international flights.

VIII. INTERNATIONAL COOPERATION AND SPACE LAW

On 25 February the Russian Space Agency was created, followed on March 2 by creation of the National Space Agency of Ukraine. On 26 May Russia and Kazakhstan, where the Baikonur Cosmodrome is located, signed an agreement to cooperate on space programmes.

On 28 February a task force of the Canadian Space Agency (CSA) presented a new plan to the Agency's directors for submission to the Canadian Cabinet. The plan calls for increased emphasis on space science, reopening and upgrading of the Churchill research range, development of a Canadian space launcher and a new, small science satellite system.

In March United States President Bush set a precedent for purchases of space equipment from the former Soviet Union by authorizing the sale to the United States government by Russia of two unfuelled Topaz thermionic nuclear space power reactors (see above) and SPT-70 Hall-effect ion thrusters, both for evaluation by the United States Strategic Defense Initiative Organization. The purchase of Russian plutonium-238 fuel for United State isotope power sources used in space was also approved, as was the sale of SPT-100 thrusters to a United States company, Space Systems Loral, for evaluation in satellite stationkeeping. On 25 March ESA, too, approved for the first time over 20 contracts between its con..actors and Russian counterparts, focusing mainly on the since-cancelled Hermes programme.

A much more comprehensive agreement between the United States and Russia, signed by Presidents Bush and Yeltsin on 17 June, eliminates many trade restrictions contained in the previous (1987) space agreement between the United States and the former USSR. It calls for close ties between NASA and the new Russian Space Agency, sets general guidelines for purchases of Russian products and services by United States

industry and government agencies, and allows one launch of a United States-built satellite by a Russian vehicle. Specific projects (see above) include launching United States astronauts to Mir and Russian cosmonauts aboard the Shuttle, joint support for the Russian Mars 94 and Mars 96 missions, and docking a Shuttle to the Mir space station.

On 19 March Germany eliminated the requirement for satellite operators to use the government agency, Deutsche Bundepost Telekom, allowing them to book space via the telecommunications agency of any signatory of Eutelsat or Intelsat. It is expected that the resulting competition will serve as an incentive to reduce prices for transponder leases.

A landmark legal precedent was set in April when a United States judge ruled that the government has a right to change its policies even if those changes affect NASA contracts. The decision in favour of NASA was made after two satellite operators, American Satellite Company and Hughes Galaxy Communications, sued the agency for the extra costs they incurred in transferring to commercial launch operators when NASA deleted their payloads from the Shuttle manifest after the Challenger accident in January 1986.

On 27 May the Czech and Slovak Federal Republic joined Intelsat, receiving a 0.5% ownership share to become the organization's 123rd member.

On 19 June ESA and Japan renewed and expanded their agreement to cooperate in space in the areas of Earth observation, telecommunications, space science, space transportation, the space station, and space-station precursor flights. Germany subsequently signed an independent cooperative agreement with Japan covering automation and robotics, environmental research, remote sensing, space transportation, reliability, and quality control.

Several other bilateral and multi-lateral agreements to conduct cooperative space activities were concluded among various countries in 1992. Additionally, several important legal cases were litigated in national courts and others remain pending, particularly in the United States.

Several important conferences and colloquia dealing with various apects of international space law were held, including one at the World Space Congress in Washingon, DC, sponsored by the International Institute for Space Law (IISL) and one at the European ISY Conference in Munich, Germany co-sponsored by the European Centre for Space Law (ECSL) and IISL.

PART TWO: PROGRESS OF SPACE RESEARCH 1991-1992

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

A. Research Activities

1. Meteorology and Climatology of the Lower Atmosphere, Including Fundamental Dynamical Processes in the Oceans

(a) Overview and Recent Research Results

The last two years have seen successful launches of satellites with active microwave instrumentation. These include the Russian Almaz-1 and Okean-3 satellites, the European Remote Sensing satellite, ERS-1, the Japanese JERS-1 and the joint US-French Topex/Poseidon satellite. The Synthetic Aperture Radar (SAR) aboard Almaz-1, ERS-1 and JERS-1 are new and powerful tools for the monitoring of the land, oceans and cryosphere, providing radar images with resolutions on the order or deka-metres.

The global measurements of wind speed and wave height, with scatterometers and radar altimeters, respectively, are expected to give a new understanding of ocean circulation and, thus, are an essential contribution to the World Ocean Experiment (WOCE) of the World Climate Research Program (WCRP). Efforts have been made to use surface wind speed data over the oceans in real time in analysis and assimilation schemes of global weather forecast models. This will lead to improved analyses for numerical weather forecasting, which, because the analyzed fields usually constitute the best global data sets, is also extremely relevant to climate research. The international exploitation of data from the new microwave instruments is rapidly progressing and new ways of data distribution have been and will be sought. There is a considerable demand for the data and products, evidence of which, for example, is the large number of requests for ERS 1 data.

A Meteor-3 flight in 1993 is planned to carry the French-Russian-German SCaRaB instrument for measuring the Earth's radiation budget components.

The capability for monitoring small spatial scales has been enhanced by the launch of the second Indian Remote Sensing satellite (IRS-1B) which provides high resolution visible and near infrared images from a Sun-synchronous orbit. The Indian satellite complements the existing SPOT and Landsat programmes, the continuity of which has been recently ensured by political decisions in France and the United States, respectively.

A new era of space observation of the chemical composition of the upper atmosphere has commenced with the advent of the United States Upper Atmosphere

Research Satellite (UARS) that was carried into space onboard the Shuttle Discovery. United States polar meteorological satellites have proved to be a continuing success for pure research as well as for applied science activities. The National Oceanic and Atmospheric Administration (NOAA)-12 satellite is the latest in this series. Geostationary observation capacity has been improved through the launch, in March 1991, of the European Meteosat-5. Its first image was received on 3 April from a 4 degrees W position. Since then it has remained the back-up satellite for the prime Meteosat-4 in its nominal position at 0 degrees longitude. Meteosat-2 marked its 10th anniversary in space with a final image. Its remaining propellant was later used to remove it from the geostationary orbit.

An important event for the atmospheric space science community was the move of Meteosat-3 to an operational position of 50 degrees W, to alleviate the present situation where only one GOES spacecraft is available. A contract between NOAA, the European Space Agency (ESA) and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) permits the repositioning of Meteosat-3 at an even more westward location. The enhanced Earth monitoring possible from this location will benefit international research activities such as the International Satellite Cloud Climatology Project (ISCCP). Meteosat-3 was also instrumental in the tracking of Hurricane Andrew in its approach to the coastline of Florida, United States.

While space observation platforms are the principal tools of space research, their use is limited without adequate access to the data. Scientists have realized that present methods of data distribution are far from ideal and most space agencies and agencies depending on space observations have therefore embarked on ambitious programmes in order to improve the utilization of Earth observation data from space. It is expected that the efforts will continue over the next decade and will result in advanced data systems enabling real time monitoring of the environment. Projects initiated in this area include the generation of the NOAA/NASA Pathfinder Data Sets which are made available to the global change research community.

Data sets from meteorological satellite are a unique source of long-term records that are continuous and consistent, which constitute the benchmark for analyzing and understanding global climate trends. During the International Space Year (ISY - 1992), the matter of a Global Change Data base received wide attention. A United Nations conference on ISY, held in Boulder, Colorado, United States, helped foster improved international cooperation in various areas of remote sensing and regional/global monitoring.

2. Dynamics, Geochemistry and Climatology of the Middle Atmosphere

(a) Overview of Recent Research Activities

Achieving an understanding of changes in the chemical composition and the structure of the middle atmosphere, due to natural and anthropogenic causes remains

a significant challenge for the scientific community. Detailed studies have been focused on the role of heterogeneous gas-phase chemistry in ozone depletion over poles and the mid-latitudes. Coupling between dynamics and chemistry in the stratosphere is also a major focus, since ozone- depleted or chemically-perturbed air from one latitude may be transported to the others. Monitoring programmes such as the Network for Detection of Stratospheric Change, *in situ* aircraft and new satellite measurements (e.g. UARS), coupled with modelling studies, are providing useful insights into changes in the stratosphere.

(b) Results of Recent Earth Observation Experiments

The United States National Aeronautics and Space Administration (NASA) on 12 September 1991 launched the UARS spacecraft into a near-circular orbit. The UARS observatory carries nine instruments which collect data on winds, temperature, atmospheric constituents, and energy input into the Earth's atmosphere. The goal of the mission is to improve scientists' understanding of the physical and chemical processes which determine the structure and composition of the stratosphere, mesosphere and lower thermosphere, with emphasis on global ozone change. Initial data from the Improved Stratospheric and Mesospheric Sounder (ISAMS), developed at Oxford University (United Kingdom), the Microwave Limb Sounder (MLS), and the Cryogenic Limb Array Etalon Spectrometer (CLAES) instruments are being analyzed. These three instruments obtain limb emission data, including temperature information, and the detection of ozone, water vapour, and various odd-nitrogen and active chlorine species. These data have for the first time provided information on the global distribution of several species.

The ISAMS data exceeded expectations for its quality and consists of many millions of vertical profiles of temperature and minor constituents in the middle atmosphere. Validation and correlation work has been carried out using Lidar soundings in France, the American National Meteorological Center's data network, ground-based observations from Table Mountain, California, United States, and profiles measured by other instruments on UARS.

Interesting and significant events or features already observed in the data include a large, sudden warning in the stratosphere, a "Noxon Cliff" in the high-latitude distribution of nitrogen dioxide, non-local thermodynamic equilibrium (LTE) effects in the emission from water vapour, large enhancements in the abundance of carbon monoxide over the winter poles (where production is minimal), and large diurnal effects (due to photochemistry) in the stratospheric abundances of active nitrogen compounds. Rather unexpected effects include the signature of the South Atlantic anomaly and of the Mount Pinatubo volcano in the Philippines.

Of particular interest is data for chlorine monoxide which plays an important role in the so-called Arctic ozone hole phenomenon. Data on various halogen compounds

obtained by the Halogen Occultation Experiment (HALOE) are also being analyzed at this time. HALOE makes use of absorption measurements using a solar occultation technique.

Horizontal wind data for the mesosphere obtained from two instruments, the Wind Imaging Interferometer (WINDII) and the High Resolution Doppler Imager (HRDI), are now available. These data are of considerable scientific interest because they represent the first near-global wind distributions for the mesosphere. Measurements of the solar ultraviolet spectral irradiance are also being provided by the Solar Stellar Irradiance Comparison Experiment (SOLSTICE) and the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM). Comparisons of various UARS data with model results demonstrate the success of simulating many aspects of the observations. UARS data are being used in the NOAA stratospheric monitoring program and in meteorological analyses produced by data assimilation techniques at the United Kingdom Meteorological Office. The UARS data are undergoing extensive validation and are being used in some preliminary scientific studies.

The Along Track Scanning Radiometer (ATSR) was launched on the ERS-1 satellite on 16 July 1991. The data are being used to study cloud heights and optical depths. In principle it is possible to determine both parameters by the use of dual angle viewing. In practice, though, inhomogeneities, foreshortening and cloud motion make this difficult. However, case studies already show that thin and thick clouds are easy to detect and distinguish, something that was difficult with conventional nadir-viewing sounders.

The Eureca Occultation Radiometer was launched in August 1992 on the European Retrievable carrier (EURECA). Early, and as yet unvalidated results from the high quality data include what appears to be higher than expected water vapour absorption at 100-km.

A data set of total ozone amount derived from observations on the NOAA series of polar environmental satellites has now been assembled for the period 1979-1992. These observations were made with the infrared sounders on the various satellites operating during this period. The data set is being analyzed in two ways, through an analysis of the time history of the annual depletion of ozone over Antarctica and through the time history of globally-distributed total ozone amounts. These data will eventually be combined with information derived from the Solar Backscatter Ultraviolet (SBUV/2) instruments that have been flying on NOAA satellites since 1985, to arrive at a consistent and credible ozone time series usable in climate and global change studies.

Finally, the Russian Meteor-3 satellite, launched in August 1991, carried a NASA Total Ozone Mapping Spectrometer (TOMS). This instrument has the important task of extending the present ozone monitoring with the TOMS aboard Nimbus-7, the satellite that confirmed the Antarctic ozone hole in the stratosphere.

3. Geology and Productivity of the Land Surface and the Oceans

(a) Geology

With the launch of synthetic aperture radar (SAR) systems on the Russian Almaz-1 satellite and on the European ERS-1 in 1991, and on the Japanese JERS-1 in 1992, new and powerful tools became available for mapping structural and tectonic features and for geomorphological investigations. Research projects on applications and data analysis techniques in geology, based on the new sensors, have been initiated in various countries. Receiving stations on all continents, including Antarctica, enable ERS-1 SAR data acquisition over all of the main land masses.

Satellite imagery from high resolution optical sensors is being widely applied for lithological and geomorphological mapping and as an aid for the exploration for mineral resources. Of particular interest for lithological mapping and spectral discrimination of Earth-surface materials are the Thematic Mapper (TM) on Landsat and the Optical Sensor (OPS) on JERS-1, both including broad spectral bands from the visible to the short infrared wavelength.

In addition to applications for the localisation of mineral resources and the identification of alteration zones, satellite imagery was found to be particularly useful for hydrogeological assessment in semi-arid zones. Successful applications have been reported from French remote sensing institutions in cooperation with local authorities, using SPOT imagery combined with ground- based information for the assessment of aquifer recharge of the main cities in Bolivia, for the selection of areas suitable for the establishment of irrigated plots in the Sahel zone, and for the assessment of storage capabilities of surface water for agricultural use in North Africa. Hydro-geomorphological maps for drought prone areas in India, showing probable ground water zones, have been derived from satellite imagery.

Another important application of high resolution visible and infrared satellite imagery is disaster prevention and damage assessment. For mapping of hazard zones and assessing the risk potential, the following information derived from satellite imagery has proved to be useful: topography, geomorphology, hydrography, structural geology, soil types, and land use. Satellite-based studies on earthquake and landslide risks have been conducted for Bolivia, Columbia and Peru. Volcanic eruptions and lava flows have been observed with satellite imagery over the Barren Islands.

Precise positional measurements from satellites are an important information source for the Europrobe project studying the lithospheric movement on the European continent, and the Balkanprobe experiment investigating the neotectonics and geodynamics of Bulgaria and the Balkan peninsula. Another Laser Geodetic Satellite (LAGEOS) was recently launched by NASA. This satellite will complement other

LAGEOS satellites in the provision of information that will lead to a better understanding of plate tectonics and Earth rotation and wobble characteristics.

Airborne experiments with advanced sensors have been carried out in preparation for future Earth orbiting systems. The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) with 224 spectral channels and the Thermal Infrared Multispectral Scanner (TIMS) in the 8-14 micrometre region, both operated by NASA, were found to provide significant improvements over broad-band sensors for identification of individual minerals and mineral mixtures, and for the characterization of mineralogical variation. The polarimetric Airborne Synthetic Aperture Radar (AIRSAR) of the United States Jet Propulsion Laboratory (JPL), which operates at P-, L- and C-bands (68, 24, 6-cm wavelengths) provides quantitative information on surface characteristics and morphology of rocks and soil, which is highly complementary to the optical sensors. Extensive multidisciplinary campaigns, including geological experiments, were conducted with AIRSAR, AVIRIS and TIMS in May 1991 in the United Stats and in June and July 1991 in Europe.

(b) Land Productivity and Environmental Surveillance

Satellite-derived information on the productivity of land surfaces is being used at different spatial and temporal scales. Regional inventories of crop acreage generally utilise a combination of high spatial resolution satellite data and ground- based information. A pilot project on the use of remote sensing in combination with agro-meteorological modelling for agricultural inventorying and monitoring is being conducted by the Joint Research Centre (JRC) of the Commission of the European Communities (CEC), aiming at the assessment of regional crop inventories and the estimation of crop yields. India has successfully used satellite data for pre-harvest production estimates for wheat, soybeans, peanuts and cotton.

Near real-time vegetation conditions on a large scale are in general based on data from the Advanced Very High Resolution Radiometer (AVHRR) of the polar orbiting NOAA satellites. Research studies on the utility of AVHRR-based indices in India, Bangladesh and Pakistan, have shown that the vegetation index was a good indicator of yield for regions with a high percentage of agricultural land. The Canadian Crop Information System, which monitors the crop conditions in the Canadian wheat belt, also relies on the AVHRR. NASA has produced continental-scale vegetation index data sets for the period 1981-90 for North America, South America, Africa and Central Asia.

Land cover/use mapping is another major application field of high resolution satellite imagery. In India, studies of land cover/use maps for the 15 agroclimatic zones is in progress, based primarily on data from the Linear Imaging Self Scanning (LISS) sensor on the Indian Remote Sensing satellite.

For the assessment of deforestation, one of the most critical environmental issues, satellite sensors are able to provide complete and consistent information on the extent and conditions of global forest cover. AVHRR imagery could demonstrate the rate of deforestation in Amazonia, Africa and South-East Asia on large scales. More detailed studies are based on Landsat imagery, and more recently on SAR imagery, which offers the advantage of cloud penetration. A successful pilot project on the application of SAR for monitoring tropical ecosystems has been carried out by NASA and JPL in the upland tropical forest of Belize using AIRSAR. Tropical Ecosystem Environment observations by Satellites (TREES), conducted by JRC and ESA, is a major initiative to derive extent, type and characteristics of tropical rainforests from multi-sensor satellite data. Presently, research emphasis is on the development of techniques for deriving information on tropical forests from SAR data.

In the United States and Canada, preparations proceeding for the Boreal Ecosystems Atmosphere Study (BOREAS), a cooperative field and analysis study, which involves elements of land surface climatology, tropospheric chemistry and terrestrial ecology. Two test sites in the boreal forests of Canada have been selected. The goal of the study is to understand the interactions between the boreal forests and the atmosphere in order to learn about the forests' role in global change. For the First ISLSCP Field Experiment (FIFE) that took place in Kansas, United States in 1987 and 1989, 225 megabytes of surface data have been placed in the FIFE Information System and these are available to the scientific community through the NASA Pilot Land Data System (PLDS).

Visible and near-infrared satellite imagery, in particular Landsat TM and SPOT, is the basis for the assessment and monitoring of pollution-induced forest damage in Eastern and Central Europe.

There is significant interest in the application of satellite data to hydrological monitoring and forecasting. Hydrological research, as well as applied projects, are carried out on the use of satellite data for snowmelt runoff monitoring and forecasting in the Himalayan mountains, in the Alps, and in mountain ranges of North America. Advancements in this application are expected from SAR data, providing all-weather data on snow extent. Pilot projects are presently carried out with ERS-1 SAR data, which can be obtained in near real-time as fast delivery products. Investigations on the extent and characteristics of the snow cover at large spatial scales are based on spaceborne microwave radiometry. Algorithms for deriving snow cover properties from Spatial Sensor Microwave Imager (SSMI) data of the United States Defense Meteorological Satellite Program have been developed in America and Europe, and are being applied in Canada for hydrological applications in near real-time.

Another promising field for the application of microwave remote sensing in hydrology is soil moisture monitoring. Successful experiments on the estimation of soil moisture have been carried out in the United States and Europe, using multi-frequency

SAR, as well as microwave imaging radiometers. The first promising results on the assessment of changes of soil moisture content have also been obtained from multi-temporal ERS-1 SAR images. In Germany the Cloud Experiment Oberpfaffenhofen and Transport (CLEOPATRA) experiment was conducted from May to July 1992, involving the 3-frequency airborne SAR of the German Aerospace Research Establishment, the AIRSAR of JPL, SAR imagery of ERS-1 and JERS-1, as well as various optical sensors. This experiment, designed to assist in the quantification of the hydrological cycle on a regional scale, is a contribution to the Global Energy and Water Cycle Experiment (GEWEX).

(c) Ocean Productivity and Pollution Monitoring

Canada and the Joint Research Centre of the CEC are leading a project on "Productivity of the Global Ocean", as a contribution to International Space Year (ISY) activities. Within this project an archive of ocean parameters such as reflected radiance corrected for atmospheric effects and derived planktonic pigment distributions is being established based on Coastal Zone Color Scanner (CZCS) data of the Nimbus-7 satellite from the period 1978 to 1986. The satellite data on ocean color are a basic contribution to the estimation of primary productivity for entire ocean basins, which is of great importance for estimations of gas exchange between the oceans and the atmosphere. Detailed studies on temporal and spatial variations of coastal upwelling are carried out for the North West African upwelling area and the West coast of the United States, based on CZCS and NOAA AVHRR data. In these areas, cold, nutrient rich water is coming to the surface, resulting in high biological activity. Such efforts may provide a contribution to the Joint Global Ocean Flux Study (JGOFS).

Sea surface temperature maps, derived from polar-orbiting and geostationary meteorological satellites, are being processed on a regular basis in several countries and disseminated to users for operational applications like identification of potential fishing zones. ESA, in cooperation with several European countries and Canada, is carrying out demonstration projects on the use of near-real time ice formation derived from ERS-1 SAR data, which was found to be of great value for icebreakers, fishing fleets, other offshore activities and the guidance of field research.

Monitoring the pollution of coastal areas is another important application of satellite imagery. Images from Landsat TM, CZCS and NOAA AVHRR were found to be useful for identifying and monitoring abnormal productions of algae in the Adriatic Sea and the North Sea and for detecting industrial waste disposals in areas with low water depths. Experiments on the detection of oil spills have been carried out with ERS-1 SAR imagery, and these indicate a good capability for detecting oil slicks at low wind speeds.

In the United States, progress continues in the development of the Sea-viewing Wide Field Sensor (SeaWiFS) satellite scheduled for launch in 1993. The sensor will

provide ocean color measurements with high accuracy, representing a major improvement over the useful data provided by the CZCS that flew successfully on the Nimbus-7 satellite. SeaWiFS will provide basic information for scientific applications in oceanography, ocean/atmosphere exchange and climate research, and will be of interest for pollution monitoring and fishing activities.

4. International Cooperation

The Committee on Earth Observation Satellites (CEOS) published a report entitled "The relevance of satellite missions to the study of global environment," prior to the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, in June 1992. The report sets out a coordinated plan, including existing and planned Earth observation satellite missions for the next 15 years. It provides a statement of the collaboration and commitment being made by those nations with access to satellite technology to achieve a truly global observing system for the environment. The report focused on the relevance of these space missions to international environmental programs. This reflects the current emphasis on global environmental changes and does not diminish the value of satellite data for environmental purposes at a regional or national level.

The CEOS report noted that over a dozen satellites currently provide data about the Earth and its environment. These satellites are a source of valuable information and are improving our ability to understand how the Earth is operating and the environment is changing. These data cover the whole spectrum of the environment including the atmosphere, land, ice, snow and oceans. The current data flow itself presents a challenge to scientists and environmentalists who must harness the resources to utilise the data and extract the information that is relevant to their needs.

The missions planned for the future will provide a significant increase in data over ongoing missions and are a clear statement of the contribution to be made by those nations with access to satellite technology. In total, some fifty space missions are planned and they will satisfy many of the currently known requirements for studying the global environment. These requirements are drawn from the programmes of the World Meteorological Organisation (WMO), the International Council of Scientific Unions (ICSU), the Intergovernmental Oceanographic Commission (IOC), the United Nations Environment Program (UNEP) and Food and Agriculture Organisation (FAO) and the Commission of the European Communities (CEC). They include major international, interagency programmes such as the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), the World Climate Research Program (WCRP) and the International Geosphere-Biosphere Program (IGBP). CEOS members recognise that the requirements themselves will change and indeed in some areas still have to be defined in detail. Thus it is the intention of CEOS to strengthen the dialogue with these communities in order to ensure the maximum return - in terms of data utilisation - from the total effort and resources mobilised in support of Earth

observing space missions. The correlation of satellite missions to user programme requirements is also discussed in the report.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

A. The Terrestrial Planets

1. Venus

The NASA Magellan spacecraft has completed two radar-mapping cycles of the entire planet. Between September 1990 and September 1992 the spacecraft produced radar and topographic maps of more than 97 per cent of the surface of Venus. Gravity field measurements will be carried out until May 1993, when the mission will be concluded. The huge set of data - greater than the sum of all the information returned by all previous planetary missions - will be the focus of intensive investigations for years to come. Some highlights of the analysis so far are as follows:

(i) The density of impact craters on the surface of Venus indicates that most of the surface is younger than 800 million years. Impact craters with diameters less than 3-km have not been observed on Venus, while larger craters often show the effect of the break-up of the incoming projectile prior to crater formation. These effects are ascribed to the dense atmosphere, which is equivalent to a 300-m shield of rock.

(ii) There is no evidence of plate tectonics on Venus. Instead, the basic mechanism responsible for the landscape appears to be the outpouring of lava in various ways from magmas brought to the surface by the action of mantle plumes.

(iii) Among the many new features, either not seen at all on other planets or not found in such large scales, is a channel 1.8-km wide that extends for 6800-km, making it longer than the Nile River (6640-km), the longest channel on Earth.

2. Moon

The Galileo spacecraft carried out a successful lunar flyby in December 1990, obtaining images and maps of the near-infrared reflection spectrum for geochemical analysis of the hemisphere centred approximately on Mare Orientale. It will return for another look in December 1992.

Lunar swing-by technology, for manoeuvring and later aero-breaking experiments with the Earth's atmosphere were studied with the Japanese Hiten spacecraft in 1990 and 1991. Lunar studies will continue with the Planet-A mission, designed to study the lunar

interior by using three penetrators, each equipped with a seismometer and a heat-flow-meter.

3. Mars

The Mars Observer spacecraft was launched on 25 September 1992 from Cape Canaveral, Florida, United States. Martian orbit will be achieved on 24 August 1993. The spacecraft will be placed in a low-altitude, near-polar, near-circular orbit to provide systematic observations, over an entire Mars year, of the Martian surface and atmosphere, and to map its magnetic, gravity and topographic fields. The primary geoscience objectives include global determination of topographic, gravitational, and magnetic fields, and of the elemental and mineralogical character of space materials. The climatology objectives are a determination of the space and time distribution, abundances, sources and sinks of volatile materials and dust over a seasonal cycle as well as delineation of atmospheric structure and dynamics.

The Mars 94 mission, to be launched in 1994 from Baikonur, Kazakhstan, Commonwealth of Independent States, will place a spacecraft in an elliptical, one-day orbit of Mars, and, using a multi-experiment payload, will observe the Martian surface, atmosphere and plasma environment. In addition, it will place penetrators and small landers on the Martian surface. A radio-relay on the Mars Observer spacecraft will be used to enhance the amount of data returned from the surface in late 1995.

A Japanese Planet-B mission is planned for launch in 1996. It is designed to study the upper atmosphere of Mars with emphasis on an investigation of the changes of its composition by the interaction of the solar wind with the upper atmosphere.

The selection of ESA's next "medium size" mission will take place in the summer of 1993. Of the four candidates, one is a planetary mission called Marsnet, a set of three surface stations on Mars. If selected, Marsnet would complement the NASA MESUR programme that involves the deployment of a number of surface stations in the 1998-2001 time frame.

B. The Outer Planets

1. Jupiter

The Galileo spacecraft was launched in October 1989. Its journey to Jupiter involves three gravity assist flybys - one from Venus and two from Earth. It is presently headed for its second encounter with the Earth-Moon system in December of 1992. It will then set out on the final leg of its journey to Jupiter, arriving in December 1995. A final, major attempt to free the high-gain antenna will be made just after the Earth-Moon flyby, running the deploying engine repeatedly against its stop. Even if the mission

must be carried out with the low-gain antenna, however, a huge set of new data from the Jupiter system is anticipated.

2. Saturn

The ESA-NASA Cassini-Huygens mission was re-scoped as a result of NASA budgetary constraints. Major changes included the elimination of both the turntable for fields and particles experiments and the scan platform for the remote sensing instruments. The new launch date is October 1997 with the arrival at Saturn projected to be 2004.

C. Small Bodies in the Solar System

1. Asteroids

The Galileo flyby of Gaspra on 29 October 1991 was a great success. The asteroid was found to be about 19x12x11-km, which is consistent with he shape and size estimates based on previous ground-based observations. It is an extreme S-type object, probably rich in olivine. The average age of a Gaspra-size object in this part of the asteroid belt is about 500 million years, while the crater density on the surface of Gaspra suggests an age of 200 million years. The Galileo spacecraft will conduct a flyby of the asteroid Ida in August 1993.

Studies for further asteroid missions are in preparation by different agencies or institutions, especially in the context of small, low-cost spacecraft.

2. Comets

The re-scoping of the Cassini-Huygens orbiter also led to the cancellation by NASA of the Comet Rendezvous Asteroid Flyby (CRAF) mission, originally designed as a partner to Cassini-Huygens. There is no comet mission under development at the present time in the United States.

A purely European mission scenario has been studied by ESA as an alternative to the original ESA/NASA collaboration for a Comet-Nucleus Sample-Return. A comet rendezvous mission with in-situ probing will be the candidate ESA Planetary Cornerstone mission when the agency at the end of 1992 selects its third Cornerstone mission.

In parallel to cometary space missions, under German sponsorship, KOSI-laboratory experiments are attempting to simulate the physical properties and behaviour of cometary surfaces. The results are of interest for the interpretation of existing cometary data and for the planning of future cometary missions.

D. International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG)

The CSTG has promoted and fostered space tracking activities on an international level for various projects directed at high precision requirements of space geodesy, geodynamics and other disciplines. Widely used techniques now include satellite laser ranging (SLR), lunar laser ranging (LLR), very long baseline interferometry (VLBI) and Global Positioning System (GPS). The new Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) technique is beginning to make scientific contributions and Precise Range And Range-rate Equipment(PRARE) is expected to contribute in the near future. Some of the major achievements within the reporting period are summarized below.

1. International Earth Rotation Service (IERS)

The IERS began operation on 1 January 1988, and is directed by a board consisting of representatives from the International Astronomical Union (IAU), the International Union of Geodesy and Geophysics (IUGG), and coordinators from each of the contributing space techniques. The IERS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and is located at the Paris Observatory. The IERS uses VLBI, SLR, LLR and GPS to define and maintain a conventional terrestrial reference frame, to determine Earth orientation parameters, and VLBI for defining and maintaining a conventional celestial reference frame based on extragalactic radio sources. During the reporting period, active campaigns using GPS were initiated, as described in a later section of this report. The IERS designated the Communications Research Laboratory (Japan) and Haystack Observatory (United States) as Technical Development Centres.

2. VLBI Activities

The basic measurement of VLBI is the time delay between the arrival of signals received at two or more ground-based antennae from distant radio sources, typically quasars. The determination of the time delay is obtained from the cross-correlation of the recorded quasar signals. The geodetic applications of VLBI measurements include the determination of the vector distances between the participating observatories and parameters that describe the orientation of the Earth in space, with respect to the quasars.

The longest regularly operating VLBI network is known as IRIS-A, which has consisted of radio observatories operating in the United States (Westford, Mojave and Richmond) plus observatories in Europe (Germany and Sweden). Additional observations are provided by the NAVNET, which includes observatories at Greenbank, Kauai and Fairbanks, United States. The IRIS-A suffered the total loss of Richmond in August 1992 when the system's antenna was destroyed by Hurricane Andrew. In

addition, the Kauai station was inoperable for several weeks after hurricane damage in September.

IRIS-P, which began in 1987, consists of the observatories in the United States (Fairbanks and Mojave), Japan (Kashima) and Australia (Hobart). A new antenna in Japan (Mizusawa) is scheduled to join the network in 1993. A southern hemisphere network (IRIS-S) consisting of Hartesbeestoek (South Africa), Hobart and the Antarctic has begun operation. In January 1991, successful experiments were made between the Japanese Syowa (Antarctic) station and the stations at Kashima and Tidbinbilla (Australia). In early 1992, Germany began Antarctic VLBI experiments at O'Higgins and the United States is expected to conduct experiments at McMurdo by 1995. Other southern hemisphere activities include the development of a VLBI system in Brazil, expected to start observations in 1993.

Systems in China and Italy have begun experiments. A new network in Russia, known as Quasar, is being deployed and initial observations have been made. Collaboration between Quasar and other networks has enabled progress toward standardization of data formats and for conducting special experiments.

Further information about VLBI, especially contributions to the IERS, can be found in the IERS Annual Reports (published by the IERS, Paris). A CSTG Subcommission on VLBI, known as the IRIS Subcommission, also issues regular reports.

3. Laser Ranging Activities (SLR and LLR)

A global network of laser ranging stations cooperate in the laser tracking of several satellites. The basic satellite laser ranging (SLR) measurement is the round trip time required for a laser pulse to travel from the transmitting observatory to a satellite, where it is reflected, and back to the observatory. In the case of lunar laser ranging (LLR), the targets are reflectors implanted on the lunar surface during the Apollo program and by the Soviet Lunakhod vehicles.

Primary SLR targets include Lageos 1 (altitude: 5900 km; inclination: 110 degrees) and Lageos 2, launched in October 1992, a collaboration between Italy and the United States. Lageos 2 is at the same altitude as Lageos 1, but the inclination is 55 degrees. Current targets include the ERS-1 satellite and the United States-France Topex/Poseidon oceanographic satellite, launched in August 1992. Other targets include the two Russian Etalon satellites (altitude: 19000 km; inclination: 63 degrees), the French Starlette (altitude: 1000 km; inclination: 50 degrees) and the Japanese Ajisai (altitude: 1500 km; inclination 50 degrees). The primary purpose of the geodetic satellites is for determination of reference frame, Earth rotation parameters, and determination of the Earth gravity field (including temporal variations). In the case of ERS-1 and Topex/Poseidon, the primary goal of SLR tracking is the accurate determination of the

spacecraft orbit to support the interpretation of on board altimeter measurements. In the case of Topex/Poseidon, the orbit must be known to an accuracy of 13 cm, globally.

In 1992, active transportable SLR stations were deployed to support crustal motion measurements in the Mediterranean as well as to support tracking of the oceanographic satellites, particularly the calibration of radar altimeters. In 1991, the German transportable system completed co-location measurements near Yalta (Russian Federation) and Riga (Latvia).

New SLR stations have begun to participate in international projects, including stations of the former Soviet Union at Maydanak, Dunaevec, Evpatoriya, Komsomolsk and Balkhach. A new Saudi Arabian system was tested through co-location at the NASA Goddard Space Flight Center. A CSTG Subcommission on SLR issues reports on SLR activities.

Lunar laser ranging sites include McDonald Observatory (United States), Grasse (France), Mt. Haleakala (United States), Orroral (Australia), and Wettzell (Germany). The LLR technique contributes universal time information to the IERS using the lunar reflectors implanted by the Apollo astronauts and those carried by the Soviet Union's Lunakhod vehicles.

4. GPS Activities

The role of GPS in space geodesy has continued to expand. GPS measurement campaigns have been conducted in most geographical areas of the world for the study of crustal motion, especially in active tectonic areas. Under the IERS, a global campaign (GIG-91) was organized to determine the ability of GPS to support IERS needs. The applications of the Russian Glonass satellite (altitude: 18000 km; inclination: 63 degrees) are being studied, however, Glonass-capable receivers are not yet widely available.

At the IUGG meeting in Vienna in 1991), plans were presented for the establishment of an International GPS Geodynamics Service (IGS) that could provide Earth rotation results and GPS ephemerides to support crustal motion measurements. A three-month IGS Campaign was initiated in June 1992 and completed in September 1992. During the campaign, high precision P-code GPS receivers were operated in Europe (Austria, Finland, Germany, Netherlands, Norway, Russian Federation, Spain and the United Kingdom), North America (Canada and the United States), South America (Chile, and French Guyana), Asia (Japan, Taiwan), Africa (South Africa), Australia and Antarctica. Many of these sites are located near VLBI or SLR sites. Analysis centres from the United States, Canada, Germany and Switzerland participated and demonstrated the feasibility of regularly producing Earth rotation and GPS ephemerides with delays of two weeks or less. Many of the observing sites are collaborators in the international cooperating network of GPS receivers, known as Cignet. During a two week period centred on 1 August, an intense international

campaign (Epoch 92) was conducted. Data from the campaign are currently being analyzed.

In preparation for an anticipated start of a regular service for the community, an IGS/Pilot Service was initiated on 1 November 1992. This Pilot Service, with the continued collaboration of the observing sites, data collection centres and analysis centres, will produce and make available to the scientific community Earth rotation and ephemerides until the start of a regular service.

With the launch of Topex/Poseidon which carries a GPS receiver, along with an SLR array and a DORIS receiver, the opportunity for comparing space geodetic results from different techniques on a common platform became possible. The GPS sites participating in the IGS Pilot Service are being used in combination with Topex/Poseidon. The French DORIS beacons, which number about 40, have a somewhat uniform geographical distribution in more than 20 countries.

5. Related Activities

The precise modelling of nongravitational forces has become important for support of oceanographic and geodetic applications. Special efforts are underway to improve the modelling of these forces, including the development of new Earth gravity models, such as Grim-3 (developed in France and Germany) and the JGM-1 (developed in the United States by NASA and the University of Texas at Austin). Other force model developments have been devoted to modelling of thermal imbalance forces.

The precise comparison of space geodetic results from the various techniques has been addressed by a CSTG Subcommission on Site Issues. This group has been instrumental in establishing procedures to assure geodetic site stability and has fostered the comparison of space geodetic techniques.

III. SPACE STUDIES OF THE UPPER ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

A. The Earth's Middle Atmosphere

The study of the Earth's middle atmosphere is a very active field of research involving numerous groups from around the world. Various measurement techniques are employed, such as ground-based monitoring, *in situ* sounding by rockets, and satellite remote sensing. The experiments are accompanied by modelling and by the theoretical study of individual processes.

Some examples of the activities in the last year are presented below. Occasionally, efforts are coordinated and campaigns with simultaneous measurements from more than one station are made.

The results of the international Dynamics Adapted Network for the Atmosphere (DYANA) project are now available. A total of 36 papers dealing with DYANA results were submitted in late 1992 for publication in a special issue of the Journal of Atmospheric and Terrestrial Physics. DYANA was performed in early 1990 at various places on the globe for case studies of middle atmosphere dynamics up to about 100 km. The main emphasis of this campaign was on global aspects of planetary waves, gravity waves and turbulence. Numerous ground-based, balloon and rocket borne experiments were involved.

A major field of interest in the middle atmosphere is the study of fine structure layers. Two campaigns were performed on this topic in the second half of 1991: NLC-91 and METAL. The NLC-91 campaign was performed in August 1991 at Esrange (Sweden) with special emphasis on noctilucent clouds (NLC) and on polar mesosphere summer echoes (PMSE). Both ground based (e.g. radar) and *in situ* (rocket) techniques were employed. The first campaign during NLC-91 gained special interest because it was the first time that *in situ* measurements of neutral and plasma small scale fluctuations were performed during a strong PMSE event, as detected by a ground-based radar. The data showed that the upper part of the double layered PMSE was consistent with turbulence theories, whereas in the lower part a non-turbulent mechanism must have been operating to create the plasma fluctuations and hence radar echoes. Publication of the results is in progress, and a special issue of Geophysical Research Letters is planned for publication in early 1993.

The main aim of September 1991's METAL campaign was to understand the creation mechanism of sudden sodium layers (SSL) and sudden iron layers (SIL) and their relationship to the sporadic E layer. A total of 6 sounding rockets were launched at times when the ground based iron lidar detected a SIL. The ionosphere was monitored by ionosondes and by the EISCAT radar.

Meteorological data obtained during the NLC-91 and METAL campaigns provide complementary data on the seasonal behaviour of the thermal and dynamical structure of the middle atmosphere at high latitudes. The transition from summer to winter conditions was confirmed to occur surprisingly fast, on a time scale of one to two weeks. In order to study the corresponding transition from winter to summer conditions, a campaign called Aerosole was performed in Andoya in spring 1992 involving meteorological rockets. The data analysis is in progress.

In late 1991 a latitudinal segment of the lower and upper atmosphere was studied in detail during the passage of the German research vessel Polarstern through the Atlantic Ocean. The vessel was equipped with numerous instruments to study

the atmosphere, such as lidars, ionosondes and OH spectrometers. Various measurements were taken from 70 degrees N to 70 degrees S, some of which extended from the ground to 100 km.

Remote sensing from the ground by lidars and radars has become a very active part of middle atmosphere research. Emphasis is put on the understanding of the creation mechanism and the morphology of gravity waves, which are known to play a crucial role in the middle atmosphere, but which are mainly generated in the troposphere and middle atmosphere. Numerous groups are studying this topic.

A major step forward in understanding the middle atmosphere is expected once the results from the Upper Atmosphere Research Satellite (UARS) are available. This satellite was launched in August 1991. The instruments onboard measure the most important constituents of the stratosphere and mesosphere, as well as temperatures and winds. Preliminary results were presented recently.

Interest in the energy budget of the middle atmosphere has increased in recent years due to the discovery that previous understandings about some of its fundamental contributions have been flawed. One example is the role of cooling by carbon dioxide and its relationship to the deactivation rate by atomic oxygen.

The coupling mechanisms between the middle atmosphere and the layers above and below have been studied both by numerical experiments and by remote sounding (mainly radar and lidar). The efforts have been worldwide, coordinated in such programmes as CEDAR (Coupling, Energetics, and Dynamics of Atmospheric Regions), UCWE (Upward Coupling of Wave Energy) and MLTCS (Mesosphere, Lower Thermosphere Coupling Study).

B. The Earth's Upper Atmosphere And Ionosphere

During the period under review there have been a relatively small number of national and international research rockets and satellites dedicated to the study of the thermosphere and ionosphere.

Following the success of the Viking satellite, Sweden, in collaboration with Germany, launched the Freja satellite in October 1992. The satellite was launched "piggy-back" on a Long March 2 Rocket from the Jiuquan Satellite Centre in China. Freja weighs 259 kg and was successfully placed in a lower orbit than Viking, i.e. in the lower part of the region where there is an interchange or interaction between the magnetosphere and ionosphere. The orbit ranges between 600 and 1720 km, with an inclination of 63 degrees. The scientific mission of Freja has many similarities with that of Viking. The auroral zone is thus the mission target and the satellite will make high resolution measurements in the upper ionosphere and lower magnetosphere. The Freja design yields substantially higher data rates than used on Viking. Freja

will be operated during a period of intense solar activity, whereas Viking carried out its mission during a period of low solar activity. This provides opportunities for extremely useful interesting comparisons.

In the field of auroral and ionospheric physics, the Puldaur rocket project is being developed by Norwegian and United States scientists to study the ionosphere during a pulsating auroral event. Launch is expected in late 1993. The Atlas-1 mission (STS-45, launched 31 March 1992) included a series of active and passive ionospheric experiments with emphasis on auroral processes. The Charge 2B sounding rocket was launched from Poker Flat by NASA's Rome laboratory on 28 March 1992 to study the emission of waves by a medium power, modulated electron beam.

Individual instruments have been flown on a number of spacecraft dedicated to other primary purposes. Examples include the Space Environment Monitors on the NOAA Tiros spacecraft which define and routinely monitor the energetic particle fluxes incident on the upper atmosphere. Future NOAA Tiros spacecraft will also carry the Remote Atmospheric and Ionospheric Detection System (RAIDS), which will monitor the density distribution of thermospheric and ionospheric species by means of limb scanning from a high-inclination orbit near 800 km altitude. The United States DMSP spacecraft will also carry instruments which measure ion drifts and field aligned currents, in addition to the energetic particle precipitation incident on the upper atmosphere. The exploitation of data from these and other orbital instruments (including instruments on spacecraft devoted primarily to magnetospheric or plasma physics research), in combination with data from networks of ground-based instruments, made it possible to carry out a series of cooperative programs for studying solar and geomagnetic activity conditions.

The primary measurements of solar and magnetospheric energy inputs to the thermosphere and ionosphere can also be used to define the inputs to global numerical models. Such models can now provide near real-time computations of the overall qualitative response of the thermosphere and ionosphere. Obtaining indices related to solar and geomagnetic activity, which faithfully reproduce the highly detailed and time-dependent patterns of auroral precipitation and plasma convection, remains a problem. There are no space missions planned for investigating one of the critical outstanding issues - the global measurement of mesospheric, thermospheric and ionospheric dynamics. These interrelated motions control many aspects of the chemical and energetic behaviour of the upper atmosphere and ionosphere. The current state of knowledge is dependent on a highly fragmentary data base and numerical models. Due to the shortage of real observational data, these numerical models have unfortunately never been validated.

The global electric circuit is largely driven by the external magnetospheric convective field at high latitudes and by the global E-region dynamo with an internal

source, mainly thunderstorm generated fields in the lower atmosphere. Investigations of the global electric circuit have been reactivated as a result of the discovery of occasional but unexpectedly large middle-atmosphere electric fields. Combined studies using rockets and ground-based radars and lidars were carried out in 1991 to observe the combined chemical, dynamical and electro-dynamical behaviour during polar mesospheric cloud periods, and during noctilucent cloud events.

The Combined Release and Radiation Effect Spacecraft (CRESS) successfully completed a second series of chemical release experiments in 1991. In July 1992 NASA sponsored the NASA/CRRES El Coqui Rocket Campaign from Puerto Rico. The campaign comprised eight sounding rockets with chemical releases and *in situ* observations and was combined with ground-based observations from Arecibo's incoherent scatter radar.

NASA's Upper Atmosphere Research Satellite (UARS) continues to provide valuable data on the lower atmosphere. The Solar Terrestrial Energy Program (STEP) is planning and implementing a number of programmes within the field of ionosphere, thermosphere and middle atmosphere physics. It should be stressed that long- term ground-based observations will play a key role in the study of the climatology of the space environment. Some progress has been made in modelling the long-term change in ionospheric variability. The combination of ground-based and space observations is particularly important in the development of the International Reference Ionosphere (IRI).

C. Planetary Atmospheres And Aeronomy

The Pioneer-Venus Orbiter spacecraft has successfully investigated the atmosphere of Venus for 14 years. This is a record in the history of space studies of planetary atmospheres. A full solar cycle of the behaviour of the Venusian ionosphere was documented, yielding a better understanding of its nature, including the mechanism of night-time ionization, winds in the upper atmosphere etc.

A new set of data about the Venusian atmosphere will eventually be provided by the entry of the spacecraft into the atmosphere as a result of the natural evolution of its orbit.

Multispectral imaging of the nightside of Venus in the near infrared during the Galileo encounter in February 1990 have been analyzed and revealed the deep cloud structure in unprecedented detail.

The deuterium/hydrogen abundance ratio is approximately 100 times larger on Venus than on Earth. This was recognized early by indirect analysis of the mass spectrometer of the Pioneer-Venus large probe data and has recently been confirmed

by ground-based measurements. This deuterium enrichment can be explained by the removal of most of the water from Venus in the early stages of its evolution.

It is also expected that the drag and torque on the Magellan spacecraft will provide important information on the atmospheric structure of Venus.

A comparison of the results of studies of aerosols in the atmosphere of Mars made by the Viking and Phobos 2 missions showed that the global dust content probably has a time scale of approximately 10 years with a reduction of a factor of three (at least for the spring season).

Analysis of another set of Phobos mission data (solar occultation spectrometry) led to the tentative identification of formaldehyde as a trace constituent in the atmosphere of Mars (abundance of about 0.0000001). The presence of this gas is still not explained and if it is confirmed will be an important sign of some non-equilibrium process in the Martian atmosphere.

A new spacecraft, the United States Mars Observer, was launched in September 1992. It will start a program of studies of the surface, atmosphere and climate of the "red planet" in early August 1993.

The Mars-94 and Mars-96 missions are being prepared in Russia for launch in 1994 and 1996 respectively. The difficult economic situation in Russia is causing problems, but, realizing the importance of maintaining the existing potential for space studies as well as the importance of fulfilling international obligations in collaborative programmes, the Russian government is supporting the projects. Scientific organizations in 20 countries are participating in the two programmes.

Mars is now a focal point for studies concerned with future international solar system studies. Many versions of a future Mars mission were presented and discussed during the 1992 World Space Congress held in Washington, D.C., United States.

D. Trace Species In The Earth's Atmosphere

A number of space missions have studied the trace gases in the middle atmosphere and lower thermosphere. The UARS satellite has provided important information on ozone distributions. Also the Imaging Spectrometer Observatory (ISO) on the Atlas-1 mission measured the OH concentration. The Exceede-3 rocket experiment measured ozone emission produced by electron beam interaction with the atmosphere.

The Task Group on International Atmospheres of Trace Species was established by the Committee on Space Research (COSPAR) of the International

Council of Scientific Unions (ICSU) in 1990. This task group is compiling information on trace species for the COSPAR International Reference Atmosphere (CIRA - part 3). Reference models which are being developed include ozone, water, nitrous acid, methane, CFCs, aerosols in polar stratospheric clouds in the middle atmosphere, and nitric oxide, oxygen and hydrogen in the lower thermosphere. In accordance with a proposal of the MAP Steering Committee of SCOSTEP, an early version of many of these reference models has just been published as MAP handbook 31 for distribution to and feedback from the international scientific community, prior to the publication of Part 3 of CIRA. The models may be used as a common means of comparison of measurements, as a common reference model for comparison for theoretical studies, and as a common input where measurements are dependent on "first guess".

The second volume of CIRA (D. Rees, J.J. Barnett and K. Labitzke, eds.) entitled COSPAR International Reference Atmosphere: 1986 Part II; Middle Atmosphere Models, has now been published by Pergamon Press in Advances in Space Research, vol. 10, No. 12, 1990 (519 pages). This book contains an earlier version of the ozone reference model (pages 315-356) being developed for CIRA-Part 3. The ozone distribution is given as a function of latitude, month and pressure (altitude) from 25 to 90 km. The tables and standard deviations are based on combined data from six satellite experiments.

At the end of 1990 the URSI/COSPAR Task Group on the International Reference Ionosphere (IRI) released the newest version of IRI. The IRI 90 handbook (155 pages) was published in November 1990 with the help of NASA's National Space Science Data Center (NSSDC) in Greenbelt, Maryland, United States as NSSDC/WDC-A-RS Report 90-22 (D. Bilitza, editor). It describes the IRI model in text and figures and summarizes the work of the IRI Task Group over the last decade. In early 1991 the IRI 90 computer software became available from NSSDC on tape, diskette, and on-line on computer networks (NSI-DECnet address: NCF::REQUEST).

In accordance with IRI's original character, the plasma temperatures in IRI at the lower boundary (120 km) are tied to the CIRA neutral temperature. The most recent version of CIRA is now used for this purpose.

The URSI/COSPAR Task Group on the International Reference Ionosphere (IRI) organized two scientific meetings in the 1991-92 time period: (1) Advances in Global and Regional Description of Ionospheric Parameters, Athens, Greece, 1-4 October, 1991; (2) Verification and New Developments of the International Reference Ionosphere, at the World Space Congress, Washington, D.C., United States, 3 September 1992. Both meetings were well attended with about 50 participants from 15 countries. Papers presented at these meetings will be published in Advances in Space Research.

An important focus of the Athens meeting was the search for better proxy indices for describing solar and magnetic conditions in the ionosphere. First plans were made for the future inclusion of ionospheric disturbances, like Spread F and Sporadic E, in IRI.

The 1992 IRI meeting, that was held during the World Space Congress, was characterized by presentations comparing IRI 90 with large ground and space data bases, including the Arecibo incoherent scatter data base, ionosonde data from the world wide digisonde network, the Goddard Space Flight Center comprehensive data base of satellite in-situ measurements, and a compilation of more than 100 rocket observations from Russia, United States and Europe. As a result of these data-intensive studies, several improvements were proposed and accepted for the next edition of the IRI model.

IRI software is obtainable from the World Data Center A for Rockets and Satellites in Greenbelt, Maryland, United States. Direct access to the most recent IRI programs and files is offered on the NASA Online Distribution and Information Service (NODIS) account, which can be reached from any of the worldwide NSI-DECnet nodes.

IV. SPACE PLASMAS IN THE SOLAR SYSTEM

The past year has seen substantial progress in this discipline with several major milestones being achieved. In February, the Ulysses spacecraft became the fifth spacecraft to fly by the planet Jupiter. Although the spacecraft was equipped with instrumentation optimised to meet the mission's prime aim of exploring the distant polar regions of the Sun's outer environment, the heliosphere, much was learned of the jovian magnetosphere during the flyby. In July the Giotto spacecraft flew by its second comet, Grigg-Skjellerup. Due to the loss of the camera during the earlier Halley encounter in 1986, the results obtained from the latest flyby of a comet were significantly weaker in output than either Halley or Giacobini-Zinner but nevertheless are important for our general understanding of comets and particularly for our understanding of the ionised environment of the comets. In September, the Mars Observer spacecraft was launched and it will no doubt return new information on the state of the upper atmosphere and the magnetism of that region and the planet itself. In October, the launch of the Swedish Freja spacecraft by a Chinese launcher marked an important step in international collaboration and also heralded the future emergence of important new data on the auroral regions of Earth following on from the extremely successful Swedish Viking mission.

The most tenuous parts of the solar system are in the plasma state, the upper levels of the Earth's atmosphere, the outer corona of the Sun, the solar wind, the ionised

atmosphere of each of the planets, the magnetospheres of Jupiter and Saturn and the extended plasma environments of comets. The bulk of our firm knowledge of the physics of plasmas in space comes from measurements made *in situ* by space probes but additional information has come from balloons, rocket probes, and ground-based facilities, such as radars.

All the planets of the solar system as far out as Neptune have now been visited by spacecraft. All planets have some kind of outer atmosphere which is ionised and which interacts with the solar wind that pervades the entire solar system. Orbiters have studied the plasma environment of Mars, Venus and an orbiter (along with a probe) is on its way to Jupiter, which this year, as noted above, has had its fifth spacecraft flyby. Three comets have now been visited by spacecraft including the comet Grigg-Skjellerup this year. Comets also have an ionised component in their atmosphere and strongly interact with the solar wind. The loss due to funding difficulties of the planned mission to rendezvous with a comet, known as CRAF, was a major blow to planetary science this year. One hopes that some form of alternative collaborative mission may emerge and that it will contain some capability for the investigation of the ionised component of the cometary environment. The joint American-European Saturn orbiter and Titan probe (Cassini-Huygens) was allied with CRAF in the United States programme, and it also suffered some serious funding problems in the early part of the year, but the project now seems secure and is to be launched later in the decade. It will certainly make major contributions to the understanding of space plasma science as the Saturn magnetosphere is rich in effects such as dust and ring plasma interactions that are unique. The moon Titan which is a major objective of the Cassini-Huygens mission has an atmosphere which directly interacts with the solar wind or the Saturnian magnetospheric material as the moon orbits Saturn.

As mentioned earlier, the Ulysses spacecraft passed Jupiter last year and is now entering the fully exploratory phase of its mission as it climbs slowly out the ecliptic plane. In mid-1994 it will be over the south pole of the Sun and in mid-1995 over the Sun's north pole. The flight out to Jupiter, where the flyby served to change its orbit to the polar orientation required for the mission, was marked by some very severe solar activity in the spring of 1991 which has led to intensive study of the suite of data obtained. The almost continuous data coverage on the cruise phase renders the in-ecliptic data set from Ulysses very important. The Jupiter flyby itself followed an orbit which none of the four earlier visitors to Jupiter had followed, allowing Ulysses to explore new regions of Jupiter's magnetosphere.

Four NASA spacecraft launched in the 1970's have now travelled to great distances in the heliosphere. Pioneer 10 and 11 are on opposite sides of the Sun, the former having passed the 50 AU mark. Voyager 1 and 2 are also in the 40-50 AU region. Plans have been made for recognizing passage through the heliopause, if and when it is encountered. The heliopause marks the limit of the Sun's direct influence in space, and the possibility of reaching this frontier is eagerly awaited.

The Galileo Jupiter orbiter making its way slowly through the solar system to its rendezvous with the planet later in the decade has also been able to monitor the solar activity this year. There is a second Galileo Earth encounter due in December 1992 and as at the first encounter in December 1990, one hopes for more solar terrestrial science from the forthcoming encounter. At the moment the failure to deploy the large antenna, essential for Jupiter orbital science, remains the major query over the long term success of the mission but all efforts have been made to maximize the return from the mission should the mission finally have to proceed without the large antenna.

The Japanese Akebono (EXOS-D) spacecraft is also continuing to provide new material concerning the Earth's magnetosphere. Akebono is one of the first spacecraft in a major internationally coordinated effort to study the solar terrestrial system. During the nineties, space agencies in the United States and Japan, the European Space Agency (ESA) in Western Europe and Intercosmos in Eastern Europe are putting together a large multi-spacecraft programme to investigate plasma processes in the near Earth space in the next decade. The next major Japanese contribution, the Geotail spacecraft, launched in July 1992 is the precursor of a coordinated international study of the solar terrestrial system. Geotail will explore the magnetotail of the Earth's magnetosphere. NASA spacecraft Wind and Polar will monitor conditions upstream of the system in the solar wind and the distant polar magnetosphere. This phase will be followed by the ESA-led Cluster mission, wherein four spacecraft will fly in close formation to study field and plasma microstructure in the magnetosphere.

The four spacecraft Cluster mission designed to study in detail processes like magnetic reconnection, hydromagnetic waves and turbulence which occur in other solar, planetary and astrophysical contexts. These can be studied *in situ* in a manner impossible in other situations. The boundary regions between the magnetospheric and solar wind plasmas are the site of a variety of anomalous plasma phenomena which are not well understood and doubtless fundamental physics will result from the first use of multi-point measurements in the high altitude magnetosphere.

The CRRES (Combined Radiation and Release Experiment) mission ceased operating during the reporting period. This had been successfully launched from Kennedy Space Center, United States, in August 1990 and it provided the first survey of the radiation belts of the Earth since the late sixties. The spacecraft probably flew the most comprehensive set of charged particle detectors ever flown on a magnetospheric spacecraft. The spacecraft also performed a series of controlled chemical release experiments in both low and high altitude to examine both the physics of the release process itself and the use of the release particles as tracers of natural phenomena. Active experimentation in space was identified in recent years as an increasing part of COSPAR Commission D's activities. The Russian Activny spacecraft was recently launched and many coordinated studies were reported at the recent sessions on active experiments in space at the COSPAR/IAF World Space Congress in Washington, D.C., United States.

Scientists in the former Soviet Union are also leading a multi-spacecraft programme,called Interball, which is also directed at the study of magnetospheric plasma processes. In some respects following on from the recent Dynamics Explorer and Viking projects of the past decade, the programme will feature pairs of spacecraft in low and high orbit respectively with the aim of further studying the interrelationship of ionospheric and magnetospheric processes.

There are many exciting programmes planned for the future in this area of research. As is regularly noted in these reports, it is important to remember that, although the core research in space plasma science must be through *in situ* measurements from space platforms, there are worldwide ancillary programmes of ground- based observations of various kinds, with telescopes, radars, magnetometer chains, riometers, etc. Often significant contributions can be made fairly cheaply by scientists working in less developed countries. Furthermore, unique measurements are made by means of balloon-borne instrumentation and instruments carried on sub-orbital rocket flights.

V. RESEARCH IN ASTROPHYSICS FROM SPACE

A. Galactic and Extragalactic Astronomy

As is well known, only a small part of the electromagnetic spectrum can reach the surface of the Earth. Access to space is therefore essential for conducting astronomy experiments throughout most of the spectrum. For those wavelengths which can penetrate to the Earth's surface, the distorting effects of the atmospheric gases may be eliminated by observing from space, even at visible wavelengths. Access to the entire electromagnetic spectrum has, since the beginning of the space age, produced many substantial discoveries and as a result led to a "golden age" in astronomy and astrophysics. As a result modern astronomers observe throughout the spectrum in seeking the most effective means of solving their astrophysical problems and the continued use of space by instruments in Earth-orbiting spacecraft is vital for further progress in the subject.

In spite of increasing budgetary pressures on many of the world's space agencies which will in turn lead to significant realignments in programmes, the past year has seen good progress in several areas of the discipline. Within the NASA program, the Extreme Ultra-Violet Explorer (EUVE) mission was successfully launched while results of outstanding importance have been achieved with the Gamma-Ray Observatory (GRO) mission following its successful launch last year. The discovery of anisotropies in the microwave background by Cosmic Background Explorer (COBE) mission attracted attention well beyond the astronomical community while at X-ray and EUV wavelengths, the continued success of the German/United States/United Kingdom ROSAT mission was especially noteworthy.

In the following sections, which are organized by wavelength range, the results achieved by the various national and international space agencies during the past year will be outlined along with the status of future missions.

1. Infrared, Submillimetre and Radio Spectra Ranges

Undoubtedly the highlight of the year was the publication by the NASA COBE investigators of the detection of a microwave background anisotropy. This result was achieved after several years of painstaking analysis and has had a major impact on our understanding of the early Universe. Further analysis of the COBE data together with hoped for confirmation by ground based techniques in the next few years should lead to an advance in Cosmology comparable to that which resulted from the original discovery of the microwave background radiation itself.

In spite of the strong support given by the Bahcall Committee to the NASA Space IR Telescope Facility (SIRTF) - a cooled 0.9m telescope for imaging and moderate resolution spectroscopy in the 2 - 700 micon range, it is now clear that under the impact of increased pressure on NASA budgets for the next several years, a new start for this programme will be significantly delayed. Given the importance of the IR spectral range, use of Small Explorer missions in this area will become increasingly important. An IR/sub-mm astronomy mission has already been selected by NASA and work is continuing for a planned launch in 1996. It is hoped that further specialist missions will be selected in this field following the recent call for Small Explorer proposals.

Given the delay in the SIRTF programme, it is unfortunate that funding pressures in both the United States and Germany have also resulted in delays to the SOFIA project which involves the construction of a 2.7 m sub-mm and far infrared telescope for flight on a NASA aircraft. This telescope would be instrumented for repeated flights above most of the Earth's water vapour to provide very high spectral resolution for wavelengths in the 30 - 350 micron range together with diffraction limited imaging at the 2.5 arc second level. It is hoped that this significant programme will be undertaken in a timely manner.

The ESA Horizon 2000 science programme includes the infra-red Space Observatory (ISO) mission which contains a cooled 0.6m telescope instrumented to observe in the wavelength range 2-200 micron with a total of four instruments capable of imaging, photometric, polarimetric and high resolution spectroscopic observations. The original launch date has been delayed somewhat by development problems and is now scheduled for mid- to late 1995. Following commissioning, ISO will be used as an observatory with approximately half of its observing time being made available to the ESA community at large during its planned 18- month lifetime. In addition, negotiations are in progress with Japan and the United States for the provision of an additional ground station which would further increase the observing efficiency of the mission.

A major mission or "cornerstone" of the ESA Horizon 2000 programme is the Far Infrared Sub-mm Telescope (FIRST) programme. Designed to explore the 50 - 1000 micron spectral range, the mission will comprise a passively cooled telescope in the 4 m to 8 m aperture class. Costing studies have indicated that it may be difficult to include instruments other than the originally planned high resolution heterodyne spectrometers, but work is continuing to further define the mission. The third cornerstone of the ESA programme will be selected in late 1993. The FIRST mission will be a strong candidate in this selection process.

Following the successful demonstration that space-based VLBI is possible, which was undertaken using the NASA-TDRSS, interesting results can be expected from the first purpose designed VLBI space missions. Using the larger M5 rocket which is currently being developed, Japan's ISAS plans the launch of a VLBI mission (VSOP) in 1995. Russia is also planning the Radioastron mission for launch around 1995. An integral part of all space-based VLBI missions is the existing network of ground-based radio telescopes, the availability of which will be essential to the success of any space enterprise in this field.

2. Optical and Ultraviolet Spectral Ranges

The International Ultraviolet Explorer (IUE) mission, which was launched in January 1978, is now in its 14th year of operation. The program is a joint one, involving NASA, ESA, and the SERC of the United Kingdom. Low and high dispersion spectral observations are undertaken in the wavelength range 1150 to 3200 Ångstrom, while the spacecraft's geosynchronous orbit ensures a high observing efficiency coupled with a unique ability to study variable phenomena. The maintenance of comprehensive data archives by the collaborating nations has greatly enhanced the value of the mission for astronomers worldwide. Operations are set to continue into 1993 and beyond. Although no immediate threat is foreseen to the continued orbital and operational life of the spacecraft, budgetary pressures in both NASA and ESA could threaten continued operation of the mission after 1993.

The NASA Far Ultraviolet Explorer (FUSE) mission, which is designed to observe at high spectral resolution in the important 150 to 1200 Ångstrom range, is likely to become a worthy successor to IUE. This spacecraft, which should be launched in 2001, will offer a significant improvement in sensitivity in the cosmologically important 900 to 1200 Ångstrom range over the Copernicus satellite which carried out the only previous observations in this wavelength interval. This mission has been highly recommended by the Bahcall Committee as part of an augmented NASA Explorer program. The mission is now in Phase B and undergoing detailed design and costing.

In December 1990, the NASA Space Shuttle carried the Astro-1 payload into orbit for an eight-day mission to observe in the 900 to 3200 Ångstrom range with a suite of three ultraviolet telescopes. A broad-band X-ray telescope of novel design was also

flown to observe a range of galactic and extragalactic sources in the 0.3 to 10 keV energy interval. Although some operational difficulties were encountered, all of the telescopes observed a large number of sources. Data analysis is now in progress, and the first results from this mission are extremely encouraging. A reflight of the ultraviolet payload is planned for 1993.

The Germany/United States/United Kingdom ROSAT mission has completed the first full survey of the sky in the extreme ultaviolet (60 - 400 Ångstrom) range using the United Kingdom Wide Field Camera instrument and a catalogue of the positions of 400 bright sources has been published. It is anticipated that a complete catalogue approaching 1000 sources will be published in the future. The mission is now well into its observatory or pointed observation phase with time being awarded on a competitive basis (see below). Several important observations of magnetic White Dwarfs have been completed and the programme is continuing.

Following the launch of the NASA Extreme Ultra-Violet Explorer (EUVE) on 7 June 1992, a further all-sky survey is being conducted in this spectral range together with some follow-up spectroscopic studies using a grazing incidence spectrometer. The instruments are operating exceptionally well, and first results from the mission are extremely encouraging. Time for use of the spectrometer will be awarded to the scientific community as part of a Guest Investigator program.

Orfeus is a 1 m class ultraviolet telescope which will operate in the 500 to 1200 Ångstrom wavelength range. A joint project of NASA and Germany, the telescope will be mounted on the German Astrospas platform and deployed from the Shuttle cargo bay during the course of an 11-day mission. Instrumentation will include three ultraviolet spectrometers provided by groups from the University of Tübingen (Germany), the University of California at Berkeley and Princeton University (United States).

The ESA Hipparcos spacecraft, launched in August 1989, failed to achieve its planned orbit and instead remained in an elliptical transfer orbit. However thanks to the outstanding efforts of the ESA project team the satellite has operated successfully and is close to achieving its original aim of measuring the parallaxes and proper motions of some 120,000 stars with a precision of 2.5 milli arc seconds. It is anticipated that the mission's operational phase will be completed by early 1994.

NASA's Hubble Space Telescope (HST), launched in 1990, was the first of the Great Observatory satellites. In spite of the well known difficulties related to the figure error in the telescope's primary mirror, results of the highest quality continue to be obtained. The use of the gravitational lensing phenomenon to probe the distribution of matter in clusters of galaxies has been particularly impressive. The work of preparing instrumentation for launch on the shuttle in late 1992 to correct several defects in the HST is now progressing well and has entered its final stages. The principal refurbishment activity involves the provision and fitting of a system of corrective optics which will essentially restore the telescope's angular resolution to the levels originally

planned. In addition, new solar arrays will be fitted so as to eliminate a small but significant pointing jitter induced by a thermal system design problem on the initial configuration. A new version of the Wide Field Planetary Camera will also be installed and, if the time available for extra-vehicular activity permits, one or more of the spacecraft's gyros will be replaced.

3. X-rays and Gamma-Rays

Following the successful launch of the NASA Gamma-Ray Observatory in April 1992, the results of more than a year's observing were reported at the 1992 COSPAR Plenary Meeting in Washington, D.C., United States. The spacecraft included four instruments: (i) the Burst and Transient Source Experiment (BATSE), which operates in the range of 0.03-1.9 MeV to locate burst and transient sources with a precision of 1 degree in a large field of view; (ii) the Oriented Scintillation Spectrometer Experiment (OSSE), which undertakes gamma-ray line observation and positions sources with 10 arc minute accuracy in the range 0.1-10 MeV; (iii) the Imaging Compton Telescope (COMPTEL), which positions sources to an accuracy of 8 arc minute within a large field of view in the 1-30 MeV range; and (iv) the Energetic Gamma-Ray Experiment Telescope (EGRET), which is spark chamber operating in the 20 MeV to 30 GeV range with an angular resolution of 10 arc min and a field of view of 0.6 arc.

Several important results have emerged, including the discovery by the EGRET instrument that many quasars emit their principal fluxes at energies in the range up to 30 GeV. The establishment of an essentially isotropic distribution of gamma-ray burst sources by the BATSE instrument has lead to intense discussion as to the origin of these objects. Although onboard tape recorder failures have led to some loss of observing time, more than 50 per cent of the data are being collected by the use of the NASA TDRSS system. It is clear that with the simultaneous and complimentary operation of the Russian GRANAT mission, the field of gamma-ray astronomy will witness major advances over the next few years.

Although the Japanese Ginga spacecraft, launched by the Institute of Space and Astronautical Science (ISAS), reentered the Earth's atmosphere, data from this most successful X-ray astronomy mission continue to be analyzed with particular emphasis on the nature of quasars and other active galactic nuclei. Work at ISAS is now focused on the final stages of preparation for the launch of the Astro-D mission which is scheduled to take place in February 1993. This mission, which includes instrumentation provided by Japanese and United States groups, will employ broad-band flux collectors of high sensitivity for observations in the 0.5 - 10 keV energy range. The use of CCD detectors with resolving power of more than 50 at 7 keV, will provide for a most effective follow-up to the ROSAT all-sky X-ray survey.

Preparations for the Russian Spectrum X mission are well advanced for launch in 1995. The spacecraft will be placed in highly elliptical orbit for enhanced observing

efficiency. It includes a wide range of X-ray instruments supplied by groups in the Commonwealth of Independent States, Finland, Germany, Italy, Switzerland, the United Kingdom, and the United States.

The Germany/United States/United Kingdom ROSAT mission has now completed its all-sky survey in the energy range 0.1 - 2.5 keV and has catalogued approaching 100,000 sources. The mission is now well into its observatory phase and has had particular success in carrying out very high sensitivity surveys so as to delineate the log N - Log S plot to even fainter sources. This work seems certain to lead to an improved understanding of the diffuse X-ray background radiation. In addition, the discovery of an enormous number of new X-ray sources in the sky will in years to come have a major impact on the entire field of astronomy.

In the NASA X-ray astronomy programme, the Broad-Band X-Ray Telescope flown successfully on the Astro-1 shuttle mission has obtained a number of striking results in the extragalactic area, in particular where new spectral observations of clusters of galaxies and active galactic nuclei have been carried out.

The X-ray Timing Explorer (XTE), which will comprise the largest area proportional counter array yet flown, is now likely to be launched on a dedicated spacecraft in 1996. With an array of scintillation detectors in addition to the X-ray proportional counters, the mission will concentrate on high temporal observations of variable sources in the energy range 0.5 to 200 keV. An all-sky monitor which can survey 80 per cent of the sky in 30 minutes is also included.

The Advanced X-ray Astrophysics Facility (AXAF), part of NASA's Great Observatory series of missions, has been reconstructed following budgetary difficulties. Two missions are now envisaged: one to be launched in 1999, which will employ a high resolution X-ray telescope and concentrate on imaging and source positioning observations and a second which is likely to be launched in the early part of the next century that will emphasize large collecting area and spectroscopic performance at the expense of angular resolution.

The X-ray Multi-Mirror mission (XMM) is the second cornerstone of the ESA Horizon 2000 programme. It comprises three separate nested grazing incidence X-ray telescopes and offers nearly 20 times more collecting area than AXAF at 7 keV, with an angular resolution of better than 20 arc seconds. The mission will therefore concentrate on high throughput X-ray spectroscopy and will thus complement the AXAF observatory. It is equipped with CCDs, reflection grating spectrometers and a separate 0.3 m optical telescope which will permit simultaneous observations to be conducted from 1500 to 10,000 Ångstrom.

In the space astronomy field, the selection process for the next ESA medium-scale mission of the Horizon 2000 programme, which will take place in the latter part of 1993, will include the Integral gamma-ray and the Prisma stellar photometry missions.

Work is continuing on the Italian SAX X-ray astronomy mission, which includes groups from the Netherlands and from the ESA-ESTEC Centre. The mission, which will operate in the 0.1 to 200 keV energy range, should be launched in 1993.

B. Solar Physics

Our understanding of the Sun, which advanced continually in the first half of this century, reached a temporary pause during the 1940's, having to a large extent exhausted the analysis possible from the limited access to the visible spectrum as seen through the Earth's atmosphere. With the advent of space rockets and the capture of the German V2 vehicles in 1946, the Sun became the first object for study in radio astronomy. Since then solar physics studies have been revitalized. Studies of the Sun have always remained in the forefront of innovative space research, and are today the most mature of all the space sciences.

Motivation for solar studies falls into three broad categories. As the nearest star and the only one for which the available spatial resolution is efficient and where access to the entire electromagnetic spectrum is unobscured, the Sun provides a unique point for the physics of stellar evolution, structure and activity. The second area concerns the Sun as a plasma laboratory. The possibility to observe the behaviour of hot plasma, the fourth state of matter, in a near steady state, is not yet available on Earth. Solar studies contribute enormously to the exploration of MHD phenomena and the collision physics and spectroscopy of highly ionized atoms. The third area is that of solar-terrestrial relations: emissions from the sun dominate the Earth's environment and provide the physical properties exploited by all forms of life on the planet. This aspect, already crucial for understanding the balance of physical processes, gains importance with the increasing awareness of global change and the evolution of the environment produced by industrial development.

1. Solar Activity

In the past three decades the greatest advances in solar physics from space occurred in the domain of high-energy emissions such as ultraviolet, extreme ultraviolet, X-ray and gamma-ray photons, charged particles and neutrons. In particular, the Solar Maximum Mission, in orbit from 1980 to 1989, through its coordinated studies over a wide range of radiations, has made very significant contributions to the understanding of flare phenomena. This emphasis on coordination will be a key element in many future projects. The space environment (free of atmospheric effects harmful to observation) has also greatly advanced certain visible light studies by coronagraphs and high-resolution imagers, which have contributed to our understanding of the role of solar magnetic

fields and of transient phenomena in the interplanetary medium. The combined observation of high energy emissions and magnetic field dynamics represents a key strategy for understanding the mechanism of solar flares and other transients. The launch of the Yohkoh satellite is already leading towards further important advances in our understanding.

2. The Quiet Solar Atmosphere

Since the "quiescent" solar chromosphere and corona have such high temperatures, they must be observed at shorter wavelengths in the ultraviolet and extreme ultraviolet spectra. The main problem here is to understand the mechanism whereby a small fraction of the mechanical energy resident in the convective motion of the lower, cooler photosphere is transferred upwards to result in the heating of the corona and the acceleration of the solar wind. According to the laws of thermodynamics, this transport must be effected by non-thermal means since heat cannot be transported in the direction of a positive temperature gradient. Results from spaceborne instruments, such as those flown on Spacelab, rocket flights and other missions, with the invaluable utilisation of ground-based observations, have clarified a number of issues.

We now have a picture of the three-dimensional structure of temperature and density, as well as the importance of continuous fine scale dynamic effects in the solar plasma and in the related magnetic field structures. The scale of the participating structures ranges from the limit of present-day telescopes (a few hundred kilometres on the solar surface) to large-scale unipolar regions called coronal holes. The observations demonstrate clearly the critical role of small-scale magnetic field structures in the transport process. Some of the previously proposed transport mechanisms can now be excluded, and there are some very positive pointers to the correct interpretation. Theoretical models based on either wave transport or stochastic processes may be equivalent in the final analysis, since any wave interpretation must involve extreme nonlinear amplitudes.

3. The Solar Interior

The techniques of space research are now being brought to bear on the understanding of the structure and dynamics of the solar interior and convection zone, in exploiting the new field of helioseismology. This field, developed over the past 20 years using observations from the ground, studies the modes of vibration of the global Sun, and interprets them in terms of the internal physical properties. Making observations in space removes the two obvious limitations of the day/night eclipsing and the atmospheric degradation. In particular, vehicles which orbit far from the Earth offer the possibility of long periods of uninterrupted solar viewing. The first space observations in a near-Earth orbit were obtained from the SMM satellite. More recently, while en route to Mars, the Russian Phobos spacecraft provided continuous data over

a period of many months. Preliminary analysis of the Iphir experiment on Phobos shows very fine detail on the 5-minute global p-mode spectrum, which throws important light on the excitation mechanism for the modes. Three ambitious experiments are planned for the SOHO mission. These observations will help resolve the questions posed by the enigmatic low solar neutrino flux, as well as the internal differential rotation, convection and the generation of the solar magnetic fields. Other studies are planned, e.g. the SOYA instrument to be flown on the Russian Mars 94 mission in 1994. Extensions of these techniques are planned also for other stars, with the EVRIS instrument on Mars 94 and the Prisma project under study by ESA.

4. The Solar Interplanetary Connection

Studies of the corona from space have shown the importance of the so-called "coronal holes," large areas of the solar surface with well defined boundaries, in which the corona has a much lower density. It is now accepted that these areas are those with an open field structure connected directly to interplanetary space. They are the major source of the steady solar wind and understanding them is thus crucial for the problem of solar (and stellar) mass loss and, ultimately, for stellar evolution. Their relation to the solar wind has so far been studied only in the ecliptic plane. With Ulysses, which is already producing valuable data in the ecliptic plane, it will soon be possible to examine the role of the polar coronal holes, which could show a significantly larger wind flux.

5. Recent and Future Missions and Programs

There are two major thrusts in the future missions currently being planned. The first covers the study of activity during the next solar maximum in cycle 22, with missions such as Yohkoh, balloon projects and the Flares 22 programme. The second relates to the quiet solar corona and its interaction with the interplanetary medium, with the missions Ulysses, Wind, Coronas and SOHO. In addition, opportunities will be exploited to pursue the techniques of helioseismology (SOHO), as well as to take advantage of the solar observing capabilities of certain astronomical missions (Sigma and GRO).

6. Yohkoh

The Yohkoh mission, launched by Japan in August 1991, carries a complement of instruments to monitor energetic flare phenomena and the evolution of coronal magnetic structures. This is the only satellite totally devoted to solar observations during the current maximum. Its payload includes a high resolution soft X-ray telescope (SXT) provided by the United States and a Bragg crystal spectrometer developed jointly by experimenters in the United Kingdom and United States. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope providing a much improved sensitivity, energy range, and spectral resolution than imaging detectors previously flown aboard the SMM and Hinotori missions. Higher energy X-rays, gamma rays and

neutrons are also being monitored by Yohkoh instruments. Significant improvements in temporal resolution, e.g., 2 seconds in gamma ray spectra as compared to the 16 seconds of the SMM spectrometer, should provide new insights into the understanding of the particle acceleration and interaction processes in flares. All instruments have been functioning well. After an intense investment in the complex operations control, detailed analysis is now beginning. The SXT instrument with its dramatic images, has rapidly shed light on the evolution of the corona. Movies assembled from its synoptic data show a "quiet" corona in constant change, on a wide range of time-scales. Preliminary analysis suggests a continuous outflow of coronal material from the active region sites.

7. Ulysses

Ulysses, formally known as the International Solar Polar Mission, was launched in October 1990 on its long journey to study the solar poles from outside of the ecliptic plane. During its recent passage by Jupiter, it used the planet's gravitational field to deflect its trajectory so as to pass over both solar poles at a distance of around 1 AU. Ulysses carries a variety of particle detectors for studying the solar wind*in situ*, as well as two small scintillation detectors for observing X-rays from 15 to 150 keV. Ulysses has already sent back a wealth of valuable information on the interplanetary medium near the ecliptic plane, including its interaction with the penetrating effect of the interstellar medium. It is now leaving the ecliptic on route towards the polar regions. It is thought that much of the solar wind seen in the ecliptic plane at 1 AU arises from the solar polar regions. It is therefore highly probable that the wind that we know at present is not typical of the general solar wind, which might be quite different perpendicular to the ecliptic plane. Ulysses thus offers the promise of advancing significantly the understanding of solar evolution and mass loss, with evident interest for other stars as well.

8. Sigma

Sigma is a French experiment aboard the Granat satellite of the Russian Federation. Although its main objective is to map the gamma-ray sky and locate non-solar sources, its cosmic gamma-ray burst detectors are also obtaining flare spectra up to energies of 100 MeV. Sigma is also designed to make high sensitivity and temporal resolution observations of flare emission in the 50 keV to 7.5 MeV range, and is accumulating a body of important solar data.

9. Wind

The Wind spacecraft, a component of the Global Geospace System (GGS), which is part of the International Solar-Terrestrial Program (ISTP), carries a high-purity germanium detector for the detection of X-rays and gamma-rays from solar flares and cosmic gamma-ray bursts in the 25 keV to 8 MeV energy range. In addition to gathering information on gamma-ray lines due to accelerated particles in large events, the

spectrometer provides nearly continuous monitoring of hard X-ray emission from flares, with spectral resolution superior to that of the SMM spacecraft.

10. Gamma-Ray Observatory

The Gamma-Ray Observatory (GRO), launched in 1991, is NASA's major mission in high-energy astrophysics. It carries four large instruments with the objective of obtaining comprehensive observations of cosmic sources in the 20 keV to 30 GeV energy range. GRO is also well-suited for observing solar radiation - gamma-ray and accelerated neutrons - which are evidence of the most energetic processes occurring in flares. Of the four instruments, the Burst and Transient Source Experiment (BATSE) has the greatest capability for flare observations, due to its large sensitive area. It should provide extensive high temporal resolution observations of flare emission in the 50 to 1000 keV energy range. Observations of the nuclear line region of the spectrum is being provided by two other instruments, the Oriented Scintillation Spectrometer Experiment (OSSE) and the Imaging Compton Camera (COMPTEL), while the Energetic Gamma-ray Experiment and the Telescope (EGRET), which covers the 20 MeV to 30 GeV portion of the spectrum, probes the most energetic phenomena on the Sun.

11. Coronas

Coronas is a series of Russian satellites planned for beginning in 1993 that will observe the solar atmosphere, solar activity, and magnetospheric solar effects from near-Earth orbit. The satellites will carry a number of instruments developed by groups from the former Soviet Union, in collaboration with groups from many other countries. Current plans include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as helioseismology instruments.

12. Balloon Programmes

Several countries, including China and the United States, have plans to carry out balloon observations with instruments dedicated to flare physics. Many of these will be carried out in long-duration balloon flights. In the case of the United States, the Max 91 programme includes the flight of the High Resolution Gamma-Ray and Hard X-ray Spectrometer (HIREGS), which is able to investigate the region 15 keV to 20 MeV with high spectral resolution.

13. The International Flares 22 Project

In an international effort similar to the successful Solar Maximum Year (SMY) programme of the early 1980's, the world-wide solar community is joining forces once again in a programme of flare research at the maximum of cycle 22. Flares 22 is an integral part of the Solar Terrestrial Energy Program (STEP), sponsored by the Scientific Committee on Solar Terrestrial Physics (SCOSTEP). Research on active phenomena will

require the analysis of data from many individual spacecraft and balloon experiments, as well as from highly improved ground-based observatories. Flares 22 focuses international attention and collaboration on the analyses of these data and on subsequent theoretical work.

14. SOHO

ESA, in collaboration with NASA, is developing the Solar and Heliospheric Observatory (SOHO), due to be launched in 1995. It will orbit the L1 Lagrangian point at 105 million kms from the Earth, a location that offers continuous viewing of the Sun and is an ideal site for *in situ* wind measurements and helioseismology. SOHO is the most ambitious solar project ever developed. Its instruments will probe the entire Sun, from its centre by means of helioseismology, its outer atmosphere by remote sensing visible and ultraviolet observations, and the wind at 1 AU by *in situ* studies. Instruments are being provided by European and United States consortia. The helioseismology instruments include Global Oscillations at Low Frequencies (GOLF), Variability of Solar Irradiance (VIRGO), and the Michelson Doppler Imager (MDI:SOI). These will measure global oscillations, the solar radiative output and surface magnetic fields. A detailed study of the solar atmosphere from the chromosphere to the corona is the subject of study for the Coronal Diagnostic Spectrometer (CDS), the Solar Ultraviolet Emitted Radiation (SUMER) instrument and the EUV Imaging Telescope (EIT) instruments. The higher corona will be observed by a Ultraviolet Coronagraph Spectrometer (UVCS) and white light and spectrometric coronagraph (LASCO). Combined, these instruments can measure the temperature, density, composition and velocity of solar plasma at various heights, with the aim of deriving the balance of energy and mass up to a height of 30 solar radii. The Solar Wind Anisotropies (SWAN), Charge Element and Isotope Analysis (CELIAS), Comprehensive Suprathermal and Energy Particle Analyzer (COSTEP) and Energetic and Relativistic Nuclei and Electron Experiment (ERNE) instruments will provide information on the solar wind.

15. Projects for Future Missions

A number of projects are under study in view of the obvious need to ensure further progress in solar physics in the next century. The Orbiting Solar Observatory (OSL), with a minimum lifetime of three years, is an observatory-type mission in a polar orbit, which would provide continuous data in white light, ultraviolet and extreme ultraviolet as images and spectra, with 0.1 arc sec resolution. It includes a 1-m telescope feeding a number of focal plane instruments. Commencement of the programme has, however, been substantially delayed by recent planning decisions, and it is likely that its configuration will be re-examined before further consideration is given to the project. Japan is preparing plans for its next solar mission, to follow Yohkoh, some ten years after that programme ends. Plans to extend the measurement of global oscillations in intensity to solar-type stars are also being developed. A preliminary experiment is planned for the Soviet Mars 94 mission, while a more extensive program is included in

the ESA Prisma study. These ideas, among others, could serve to ensure a bright future for solar physics at the start of the next millennium. Solar observations benefit enormously from opportunities to develop new instrumental techniques, provided by simple short missions. In this connection, the United States rocket programme has been of great value, and it hoped that this will continue in the future. The ESA EURECA programme and NASA's Spartan programme, both of which utilise the Space Shuttle, are also likely to be important contributions to this field.

VI. LIFE SCIENCES AND SPACE RESEARCH

A. Gravitational Biology

1. Space Medicine

During the last two years, a variety of manned space missions of short or long duration were performed, on the Russian orbital space station Mir as well as Space Shuttle missions SLS-1, J-1, and IML-1. The duration of these missions varied from one week up to more than six months. On the Mir station there were four visiting expeditions with cosmonauts from Germany, Kazakhstan, Austria, and France.

The permanent operation of the Mir complex was provided by seven Russian cosmonauts, one of whom, S.K. Krikalev, stayed in orbit 311 days during two expeditions.

A great volume of inflight work was accomplished including operations with seven Progress cargo spacecraft and a series of EVAs. The total duration of these operations was 50 hours.

The main result of medical support of the Mir spacecrews is the maintenance of the health, functional reserves and working capacity of the cosmonauts inflight and postflight. Data on medical and physiological studies during the flights of the Mir complex expanded scientists' understanding of the individual peculiarities of cosmonauts' adaptive responses, which enables the improvement of the medical monitoring system and the optimization of preventive countermeasures during the long-term space missions.

Neurophysiological studies of sensory systems and motor coordinating functions of the cosmonauts, including experiments done with the use of a unique research equipment complex developed within the framework of Astromir Project, further advanced the state of space medicine. These studies were began during the Russian-Austrian space mission are being continued by the Russian cosmonauts.

During visiting expeditions, with participation from German and French cosmonauts, experiments were conducted to study the physiological responses of different functional systems of the human body during space missions. The functions studied were: the cardiovascular system, fluid-electrolyte exchange and total metabolism, the neurophysic sphere and operator activities.

A great amount of human physiological investigation has been accomplished through the Space Shuttle programme. An important contribution to the successful conduct of such studies on gravitational biology and physiology has been made by the physician-astronauts regularly flown aboard the Space Shuttle.

2. Space Biology

Research in this field has been performed aboard the Space Shuttle in missions such as SLS-1, J-1, and IML-1, the Mir Space Station, through the use of sounding rockets and parabolic flights, and in laboratory simulation conditions (using clinostats and centrifuges, using head-down tilt). The analysis of biological data obtained during the IML-1 mission has been completed. Experiments with rats flown on IML-1 provided new insight into mechanisms of adaptation to microgravity at the level of circulation, muscles, CNS and metabolism. Results of the IML-1 mission were discussed in a symposium held at the World Space Congress, Washington, D.C., United States, August-September 1992.

Experiments with higher plants were continued aboard the Mir Space Station to investigate the problems of plant growth and development in weightlessness and closed biological life support systems. In further experiments with birds, the peculiarities of embryogenesis in microgravity were studied.

B. Radiation Biology

The growing interest in radiobiology was manifested by an increased in the number of scientists from this discipline involved in COSPAR and by the large number - over 150 - of presentations on this subject at the World Space Congress. The papers and poster presentations were notable for the breadth of the subject matter covered and their contributions to the understanding of radiation effects in space.

Radiation in space is predominantly protons and HZE particles and there are no human populations that have been exposed to these radiations and that are suitable for estimating the risks of cancer. In the case of HZE particles, there is also concern about late effects other than cancer. Estimates of risk to humans from exposure to radiation in space must be obtained from experimental systems, primarily through animal studies. Such studies are becoming increasingly difficult to carry out, in part because of cost. The important question of whether HZE particles could cause late-appearing damage to

the brain can be answered only with experimental animals. Recent results suggest that at least with high fluences such damage may occur.

A reassessment of the risk estimates for radiation effects, especially cancer, from exposures in low-Earth orbit is in progress in the United States. This necessary because in the time since the current recommendations about dose limits for crews on missions in low-Earth orbit were established, the estimates of radiation- induced cancer have been increased. Furthermore, the International Commission on Radiobiological Protection (ICRP) has made new recommendations about radiation protection of terrestrial workers exposed to radioactive materials.

Concern had been expressed about the lack of international agreement about dose limits that should be applied to radiation protection in space. With increasing participation between various countries in space missions and the promise of long duration missions in low-Earth orbit, some agreement must be reached.

1. Ground Research

Research on the effects of protons and heavy-charged particles requires suitable accelerators. The coming-on-line of the GSI accelerator at Darmstadt, Germany makes it possible to increase the research on the effects of HZE particles on cells and other experimental systems. Unfortunately, 1992 will be the last year that the Bevalac facility at Lawrence Berkeley Laboratory, United States, will be in operation. The closure of this accelerator is a major blow to research in biology and physics related to space radiation. It has been proposed that a comparable facility should be established at Brookhaven National Laboratory, United States, but it will be some years before suitable beams will be available for research.

However, in the last year, considerable progress was made in understanding the effects of galactic cosmic rays. The studies have been at all levels of biological organization, from the molecular to the level of the whole animal. The effects, in particular, of heavy ions on mutation, cell killing, development and cancer induction are being investigated. The experimental determination of the relative biological effectiveness of various radiations, in particular HZE particles, have a practical aspect in the estimates of risk of radiation-induced effects. Studies of the relationship between track structure and various biological effects are designed to increase the understanding of the mechanism involved.

The ICRP has recommended new radiation weighting factors and quality factors in relation to linear energy transfer (LET). It is these factors that are used to calculate the dose equivalents which are essential for risk estimates. The new values have an impact on many previous estimates and experimental studies are required to validate these new quality factors.

The nature of the shielding spacecraft influences the radiation environment within the spacecraft. An important aspect of ground research in this area is the determination of the effect of nuclear fragmentation and galactic cosmic ray transport on the radiation environment within the spacecraft. This information is essential for the determination of organ doses. The validation of the models and transport codes requires suitable accelerators.

2. Research in Space

The collection of dosimetric measurements and the development of instruments capable of giving more information about energy and LET spectra has continued. Analysis of data collected from satellites during the large solar particle events that have occurred in the last few years and from the Long Duration Exposure Facility (LDEF) have also continued. Information about the dose rate of the radiation during solar particle events is an important element of the studies because dose rates of proton radiation has an influence on the biological effects.

The termination of NASA's proposed Life Sat programme dealt a blow to the progress of research in space. This facility was to have carried experiments of scientists from a number of countries designed to elucidate interactions between microgravity and radiation. European scientists have pioneered such studies and have accumulated information about the combined effects of HZE particles and microgravity on simple organisms such as crustacean eggs, as well as various types of spores and seeds. These results were obtained from studies on the Biocosmos satellites and on the LDEF. The most recent studies have been in the International Microgravity Laboratory (IML), carried on the Space Shuttle STS 42 mission. In addition to the European studies, an investigation was conducted on mutations in nematodes. The question of the magnitude of interactions between radiation and microgravity must be settled and this requires suitable facilities in space maintained for relatively long periods of time.

C. Planetary Biology and the Origins of Life

1. Planetary Biology

As in 1991, interest in this field has continued to focus on the Mars 94 and Mars 96 missions, the joint ESA/NASA Cassini mission to Saturn and to its largest satellite Titan, and the Search for Extraterrestrial Intelligence (SETI) programme.

Regarding Mars, primary topics of interest include the problem of finding liquid water on Mars and the possibility of finding Martian fossils or records of prebiotic evolution. The evaluation of techniques to search for life (extinct or extant) continues, as has the examination of sites for exobiological studies. Other issues of general interest include the data obtained with terrestrial models for survival on Mars. Simulation experiments in the laboratory and observations in extremely dry deserts (Antarctica,

Atacama) both suggest that survival of dormant life for geological periods of time appears quite unlikely, unless the dormant organisms are "revived" after at least decades so that they can repair the DNA damage that accumulates in extreme dryness. Other issues include the question of Mars colonization and the importance of planetary protection provisions for Mars missions.

The atmospheric conditions of the Saturnian satellite Titan have been further evaluated in relation to the planned Cassini mission. Principal questions are concerned with the composition of the organic haze, the meteorological conditions (e.g. rain of small methane droplets) and aspects of prebiotic chemistry.

The SETI programme is in progress. To date, no "intelligent" radio sources have been detected.

2. Origins of Life

Progress has been achieved regarding the formation of monomeric building blocks and the formation of polymers believed to have been essential for the first life.

The traditional view of small molecules is that the formation of the simple organics essential for the origins of life formed by atmospheric lightning discharges suffers from the absence of reduced reactants, e.g., methane, ammonia and hydrogen. Consequently, the possibility that the organics necessary for the first life came from other sources, especially comets or hydrothermal systems, was examined in detail in 1992. Constraints on the delivery of organics and the possible destruction and synthesis of organics during cometary impacts were also evaluated. It has been concluded that cometary delivery of organics is at least as plausible as their synthesis by lightning discharges. Evidence of hydrothermal systems is presented in the so-called undersea"black smokers." These marine systems have also been a source of information on organics on the primitive Earth. They consist of vast areas of fluid circulating through clays and other mineral assemblages. The redox potential in these systems is strongly reducing. They work as a flow reactor in which more oxidized gases such as carbon monoxide and carbon dioxide are reduced. Because of mineral catalysis, the resultant products are converted to more complex structures. Sharp temperature gradients may serve to initiate and quench these chemical processes.

A principal area of polymer research activity is the synthesis and replication of RNA-like oligomers that may have resulted in the RNA world. The first successful polymerization of mononucleotides to oligonucleotides under plausible prebiotic conditions was reported by Ferris and Ertem in 1992. They observed the formation of oligomers as large as the decamer in the reaction of activated derivatives of 5'-AMP in aqueous solution at pH S and room temperature in the presence of montmorillonite clay. The products contain more than 80 per cent 3',5-linkages when dinucleotide pyrophosphates initiate the reaction. This study highlighted the essential catalytic roles

of minerals in the origins of life because these oligomers are not formed in the absence of montmorillonite. The template directed synthesis of RNA oligomers, a process that had previously been restricted to the synthesis of G and A oligomers has been extended to oligomers containing C and U by Leslie Orgel and co-workers. A hairpin template in which the 3'-terminal nucleotide of the hairpin serves as the primer for the oligomerization reaction is the key to the success of this approach. This study indicated that non-enzymatic template-directed replication of RNA could have included limited amounts of C and U along with A and G.

The evolution of the catalytic function in the RNA world was demonstrated by Beaudin and Joyce. They developed a laboratory model of the RNA World in which the 1013 variants of the group 1 ribozyme from Tetrahymena that cleaves RNA was generated. A selection constraint was imposed on these variants so that only those progenies that catalyze the hydrolysis of DNA were selected. Mutation of these progenies and further selection led to a ribozyme that can cleave DNA. This study demonstrates that one type of RNA catalysis could have evolved into another in an RNA World.

D. Natural and Artificial Ecosystems

1. Biospherics

Remote sensing technology has contributed to studies on the evolution of the biosphere and its current functioning. During the reporting period, particular attention has been given to the measurement of the distribution and the effects of biomass burning which impact on global changes. Particular effort has been focused on measures concerning global change. Terrestrial observation projects have not suffered from the budget limitations which have effected severely other projects, especially in Europe.

2. Ecological Life-Support Systems

The likelihood that long missions in space will ultimately be conducted has given rise to the realisation that bioregenerative systems able to produce food by plant cultivation and to regenerate oxygen and water will be needed for such missions. The new concept pf Artificial Ecosystems has stimulated research in areas such as biomass production, microbial interaction on plants and waste recycling. During the reporting period a number of teams and experimental systems dedicated to those problems were established.

In this regard, the beginning of the Biosphere II project in Arizona, United States, has generated much media attention. Although its actual scientific potential has been questioned by scientific communities and space authorities, its likely positive impact will be to accelerate plans for artificial ecosystems. Several projects with associated institutes are in development in Russia, Europe and Japan under the control of space or related

government agencies. The purpose of these projects is to contribute directly to space projects and to the knowledge of the functioning of the terrestrial ecosystem.

VII. MATERIALS SCIENCES IN SPACE

Research in microgravity science is characterized by a balance of theoretical studies, fundamental research experiments, and applications oriented experiments. Throughout the international community, microgravity research is diverse and includes the broad disciplines of materials science, biotechnology, fluid physics and transport phenomena, and combustion.

The past two years in microgravity research have been active, highly successful and distinguished by increasing international collaboration, as evidenced by the first International Microgravity Laboratory and other joint ventures. This type of interaction and cooperation enables participating nations to attain mutually beneficial goals and encourages broader international partnerships and scientific alliances that may continue into the space station era.

A. Materials Science Research

The goal of microgravity materials research is to use the unique characteristics of the space environment to study fundamental issues in materials solidification and crystal growth and thermophysical property measurement. Of particular interest is understanding the roles of buoyancy-driven convection, sedimentation, and hydrostatic pressure in the processing of electronic and photonic materials, metals, alloys, composites, glasses, ceramics, and polymers. Materials science research may lead to a better understanding of the processes by which these materials are produced, and the effects of those processes on the properties of the materials.

The NASA-sponsored Gallium Arsenide (GaAs) crystal growth experiment flew as a Get Away Special (GAS) payload in 1991 on the Space Shuttle's STS-40 mission and again on the STS-45 mission in 1992. This materials processing experiment, part of a larger effort to better understand and control the crystal growth process, was undertaken to investigate the effects of buoyancy-driven convection on crystal growth.

NASA's materials science programme sponsored several experiments on two highly successful Space Shuttle missions in 1992: the first International Microgravity Laboratory (IML-1), and the first United States Microgravity Laboratory (USML-1). The United States Microgravity Payload (USMP-1), launched in October 1992 also conducted valuable materials research.

The Vapor Crystal Growth Studies of Single Mercury Iodide Crystals experiment was conducted in the Vapor Crystal Growth System (VCGS) on IML-1. Mercury iodide crystals have practical uses as sensitive X-ray and gamma-ray detectors.

Four NASA-sponsored investigators used the Crystal Growth Furnace (CGF) on USML-1 to study the effect of gravity on the growth of a variety of semiconductor materials. Semiconductors are used in a wide variety of electronic and electro-optical devices found in consumer, military and aerospace products.

A NASA materials science experiment was conducted on the recent USMP-1 mission. The Crystals by Vapor Transport Experiment (CVTE) will provide data on the effect of microgravity on the growth of the semiconductor crystal Cadmium Telluride (CdTe).

IML-1 was also an important mission for the French National Center for Space Studies (CNES). CNES provided the Mercury Iodide Crystal Growth (MICG) facility in which the Mercury Iodide Nucleations and Crystal Growth in Vapor Phase experiment was conducted. Other space experiments recently conducted by CNES include the Casimir experiment which was dedicated to zeolite crystal growth through hydrothermal synthesis under microgravity, and the Crocodile experiment dedicated to crystal growth from a solution by double diffusion of NPP, an organic compound with a high nonlinear optical conversion efficiency (a second experiment is scheduled for 1994).

CNES sponsored a materials science experiment called Mephisto on the USMP-1 mission. This experiment conducted a variety of tests to determine how directional solidification in microgravity affects the shape, temperature and velocity of the solidification front. Data from these tests will be used to improve the understanding of fundamental behaviour of materials during solidification on Earth.

Suborbital experiments are also an important part of the French microgravity program. The Grenoble drop tube (a joint project of CNES/CEA/CNRS), which is dedicated to containerless solidification, has created a worldwide record of undercooling for a pure material (-950 for rhenium). In addition, the Caravelle airplane available to CNES allows access to parabolic flight experiments. In particular, the feasibility of the gas film levitation technique has been checked at room temperature, and the preliminary tests for a lasercooling experiment of an atomic vapor have been performed.

In addition to the Space Shuttle missions mentioned above, the Spacelab J mission also took place in 1992. A joint mission between the National Space Development Agency of Japan (NASDA) and NASA, 34 of the 43 experiments were sponsored by NASDA, 19 of them in the area of materials science. The materials research included experiments in electronic materials, metals and alloys, and glasses and ceramics. A variety of advanced materials were investigated, including amorphous semiconductors, lightweight composites, and superconducting compounds.

Sounding rockets are an important aspect of NASDA's materials science program. The TR-IA rocket series includes the first TR-IA rocket launched on 16 September 1991 and the second TR-IA launched on 20 August 1992. The third is scheduled for August/September, 1993. The first two rockets included the following experiments: (1) field observation of boundary and environment phase in crystal growth; (2) melting and solidification of particle-dispersed alloy; (3) semiconductor liquid growth; (4) melting and solidification of high-temperature oxide superconductor; and (5) melting and solidification of vitreous material.

The German Space Agency (DARA) primarily conducts microgravity materials research within a ground-based programme, highlights of which include the areas of Dopant Striations of the Second Kind and Monotectic Alloys.

B. Biotechnology Research

The purpose of biotechnology research is to use the microgravity environment to investigate bioprocessing phenomena. The two primary research areas are crystal growth of biological macromolecules and cell and molecular science. X-ray crystallography is a powerful technique for understanding the structure and functional interactions of biologically important molecules such as proteins and viruses. Research to date has indicated that protein crystals grown in low gravity may yield substantially better structural information than can be obtained from crystals grown on Earth.

NASA supports investigations to improve our understanding of the effect of variables such as temperature, pH, and gravity on crystal quality, and works with industry and academia to produce crystals of interest to biochemists. The biotechnology program also supports a broad range of research in cell and molecular science including the use of microgravity as a processing environment for potentially improved biological products, such as collagen fibres and cell cultures.

The completion of the Spacelab-J mission marks NASA's fifteenth flight of the Protein Crystal Growth (PCG) experiment which has been performed in various types of hardware. Past microgravity experiments have produced several sets of protein crystals that exhibited greater structural perfection than their best Earth grown counterparts. Examination of such crystals provides information on basic biological processes and could lead to the development of foods with higher protein content and more effective drugs. As a result the PCG experiment has more than 50 co-investigators from the academic and industrial communities.

Spacelab-J was an important mission for NASDA in the area of biotechnology. Several NASDA-sponsored biotechnology experiments were conducted on Spacelab J, including: Separation of Biogenic Materials by Electrophoresis under Zero Gravity, Crystal Growth of Enzymes in Low Gravity, and Separation of the Animal Cells and Cellular Organella by Means of Free Flow Electrophoresis.

Research in biotechnology is also being conducted by CNES. With industrial participation, the Sedex experiment was performed onboard a Photon capsule. This experiment was dedicated to the enzymatic synthesis of dextrane from saccharose under microgravity, and took place in September 1991. Several protein crystallization experiments are currently being prepared in cooperation with ESA and NASA. Also planned is a series of French experiments to be conducted in the Ramses facility which will perform continuous flow zone electrophoresis.

IML-1 was an important mission for Germany in biotechnology research. The German Aerospace Research Establishment (DLR) sponsored the Cryostat facility in which three experiments were conducted. These included Single Crystal Growth of Beta-Galactosidase and Beta-Galactosidase/Inhibitor Complex, Crystal Growth of the Electrogenic Membrane Protein Bacteriorhodopsin, and Crystallization of Proteins and Viruses in Microgravity by Liquid-Liquid Diffusion.

The Canadian Space Agency (CSA) flew five protein crystallization experiments on board the Mir space station. The proteins were launched into space aboard a Progress capsule on 25 January 1992 and linked with Mir on the 27th. The experiments were activated the following day and included the following: Anti-Brucella Fab, Fab-Hpr Complex, Nonfluorescent Flavoprotein, and Trp tRNA Synthetase.

C. Fluid Physics and Transport Phenomena Research

Microgravity fluid physics and transport phenomena research seeks to improve understanding of those aspects of fluid dynamics and transport phenomena whose fundamental behaviour is limited or affected by the presence of gravity. For example, a low gravity environment results in greatly reduced density-driven convection flows and allows the study of other forms of convection such as flows driven by surface tension gradients, magneto/electrohydrodynamics, or other interfacial phenomena. Understanding these phenomena can provide the basic scientific and practical knowledge needed to design effective and reliable space- based systems that rely on fluid processes.

NASA conducted fluid physics and transport phenomena research on IML-1, USML-1, and USMP-1. ESA provided the Critical Point Facility (CPF) for IML-1 in which the Investigation of the Thermal Equilibration Dynamics of SF6 Near the Liquid-Vapor Critical Point experiment was conducted. Research on USML 1 included the Surface Tension Drive Convection Experiment (STDCE) and the Drop Physics Module (DPM) experiments. STDCE conducted studies of fluid mechanics and heat transfer in microgravity whereas the DPM experiments were designed to study the dynamics of liquid drops in microgravity: their equilibrium shapes, the dynamics of their flows, and their stable and oscillatory behaviour.

A major experiment on the USMP-1 mission was NASA's Lambda Point Experiment (LPE). This experiment precisely measured the heat capacity of a superfluid

helium sample as it passed through its lambda transition. LPE was designed to test Kenneth Wilson's Nobel Prize winning theory of cooperative phase transitions.

CNES was involved in the fluid physics and transport phenomena research on IML-1. Two experiments were carried out in the CPF: Heat and Mass Transport in a Pure Fluid in the Vicinity of a Critical Point and Phase Separation of an Off-Critical Binary Mixture. However, the most outstanding experimental result in recent years is the evidence, via a Texus sounding-rocket experiment, of a new mode of heat transport in hypercompressible fluids.

Three experiments in the area of fluid physics and transport phenomena were conducted by NASDA on Spacelab-J. These included Drop Dynamics in Space and Interference with Acoustic Field, Marangoni-Induced Convection in Materials Processing Under Microgravity, and the Study of Bubble Behaviour.

NASDA also conducted fluid physics and transport phenomena research in its TR-IA rocket series. The first two TR-IA rockets included research in Marangoni convection generation and control, and bubble generation, growth and movement. The third rocket will include more research in these areas.

DARA's microgravity research in this area includes (1) measurements of the behaviour of density, pressure and temperature of sulphur hexafluoride at the critical point, (2) investigations on the specific heat capacity in the critical region of pure liquids, (3) liquid columns resonances (ground based experiment and a flight experiment on the D-2 mission), and (4) electric rayleigh-benard-instability.

D. Combustion Research

The objectives of combustion research are to understand the processes of ignition, propagation and extinction during combustion in a low gravity environment. This research is directed at achieving fundamental understanding of combustion processes, as well as addressing issues of fire safety in space. Ground-based and space experimentation focuses on studies of the processes of ignition, flame spreading, flame extinction and the physical characteristics of flame, such as size and shape, and soot formation and its role in combustion. Investigators also study air flows and heat and mass transfer phenomena at the combustion site for materials such as fuel vapours, liquid pools, paper and metal solids.

Spacelab-J marked the fifth flight of NASA's Solid Surface Combustion Experiment (SSCE). This experiment studies the physical and chemical mechanisms of flame spread over solid fuels in the absence of gravity-driven air flows. Data from the SSCE will be used to refine basic theories of combustion, and may help scientists and engineers to better understand and evaluate fire hazards aboard spacecraft.

E. Other

A major achievement for ESA is it's European Retrievable Carrier (Eureca) platform which was put into orbit by Space Shuttle Atlantis in August 1992. Eureca is a retrievable, reusable, fully automatic and autonomous space platform. It is equipped with 15 multi-mission instruments designed for long duration microgravity experiments. Eureca's first mission carried experiments on life sciences and on the growth of crystals in microgravity. It will be recovered by the Space Shuttle after 10 months of automatic flight and will then be sent back to Europe to be fitted with new experiments for a second flight in 1995.

ESA experiments were also flown on Russian Biosatellite missions in 1987 and 1989. These unmanned spacecraft are launched into orbit for a period of two weeks to three weeks. Biosatellite missions are an important part of the ESA microgravity research programme. Other important elements of ESA's microgravity programme are parabolic flights and sounding rockets. In February 1993, DARA will launch its second Spacelab mission, D-2, dedicated to research in all branches of microgravity science and life sciences. D-2 will be Germany's last dedicated Spacelab mission. Its programme, however, has benefitted from expanding collaboration with the former Soviet Union and Japan, which, through Intospace, a commercial space marketing firm, has funded experiment opportunities on the D-2 mission.

Japanese science Astronaut Dr. Chiaki Mukai, alternate payload specialist for the Spacelab-J mission, has been selected as primary payload specialist for the second International Microgravity Laboratory, IML-2, to be launched in the summer of 1994. Dr. Jean-Jacque Favier, principal investigator of the French Mephisto experiment flown on USMP-2, has been chosen as alternate payload specialist. With over 80 experiments planned, IML-2 will likely be the most demanding Spacelab mission to date.

VIII. SATELLITE DYNAMICS

During 1991 and 1992 there was a significant increase in space missions that required accurate orbit determination to fulfil their scientific goals. Over the past two years two new Earth satellites, Topex/Poseidon and Lageos-2 were launched for oceanographic and geodetic research. They add to the achievements of highly successful satellites like Lageos-1, Starlette, Etalon-1 and Etalon-2 and ERS-1, which were launched in earlier years, and which are still generating useful data. The analysis of the vast amounts of tracking data, acquired from all these satellites, was pursued with increased intensity. Furthermore, the Mars Observer spacecraft was sent on its route to Mars, which will provide the first highly precise altimetric measurements of a planet other than the earth. Also the "old" Giotto spacecraft was revived and guided with high precision to a meeting with comet Grigg Skjellerup. Some of these developments are described in more detail below.

A. New Geodetic and Oceanographic Satellites

The Topex/Poseidon spacecraft was launched on 10 August 1992. It is a cooperative project between the United States and France, the main purpose of which is to monitor long-wavelength ocean dynamics. The satellite carries two altimeters, SLR reflectors, and DORIS, GPS and TDRSS systems. It is the first time so many different tracking systems have been integrated onto one satellite platform which provides a unique opportunity for comparing and verifying data. The altimeters, which are the prime instruments, will measure the distance to the sea surface with 5 cm precision. The other tracking systems will enable the orbit of the satellite to be determined with an unprecedented accuracy of better than 10 cm in height. From the combination of these orbits and precise altimeter measurements, accurate models of the sea surface topography can be constructed. These models will contain the signature of the dynamic processes, such as winds and currents, that shape the ocean surface. By studying temporal changes, important information may be obtained on the subject of global change.

Another satellite, Lageos-2, was launched on 22 October 1992. Similar to Lageos-1, launched in 1976, this passive satellite consists of a sphere whose surface is covered with laser retro-reflectors. Its purpose is to provide increased SLR coverage for geodynamics investigations. Therefore, it was put in a different orbit than Lageos-1. The satellite mission was a joint project between Italy and the United States. The United States provided a Space Shuttle launch and Italy provided the satellite and the experimental IRIS upper stage. It is expected that the SLR data from this satellite will further expand the knowledge about the tectonic motions of the Earth's crust and the underlying mechanisms. The satellite will also contribute to significant improvements in Earth rotation studies which are closely related to the continuous changes in the distribution of the air and sea masses.

B. New Mars Mission

In 1992 the United States launched its first spacecraft to Mars in 17 years. On 25 September 1992 the Mars Observer started its journey and is expected to arrive at the planet in August 1993, when it will enter an elliptical orbit. Several manoeuvres, which will require precise navigation, will gradually circularize the orbit at 400 km altitude. The spacecraft carries a laser altimeter which will not only be used to map the topography of Mars, but also to accurately determine the orbit of the satellite. This will provide detailed information about the Martian gravity field, which, in turn, may yield some clues about the interior structure of the planet.

C. Improved Terrestrial Reference Frame

The International Earth Rotation Service (IERS) has generated an improved definition of the Conventional Terrestrial Reference System (CTRS), based on

contributions from many space measuring techniques. In particular the analysis of the SLR data, collected by a global network of laser ranging stations observing the Lageos satellites, has contributed significantly to this achievement. Many different international groups are involved in this effort. An important new goal is to establish the positions of the global FLINN fiducial network, which is in the course of being implemented, at the centimetre level. Considerable progress towards this goal has been made. The coordinates of the pole and Universal Time (UT) are currently being determined with an accuracy of 0.2 milliarcsecond and 0.05 millisecond, respectively.

D. New Geopotential Models

On-going efforts to produce improved gravity field models for the Earth have resulted in several new sets of coefficients up to degree 60 to 70. A significant part of the improvement was due to the incorporation of a new type of tracking data, acquired by the experimental DORIS system onboard the French SPOT-2 satellite, launched in 1990. Major benefits of this system are the all-weather capability and the good global distribution of the approximately 45 tracking beacons. Further refinement was achieved by reiterating old solutions, using the latest standards for (geo)physical constants and models. The importance of these new fields is in the areas of accurate orbit determination of other satellites and for oceanographic studies, which require good geoid models. The latest models currently allow a radial orbit accuracy of 15 to 25 cm for satellites like Topex/Poseidon and ERS-1, at altitudes of 800 and 1300 km respectively.

E. Improved Models for the Gravity and the Topographic fields of Mars and Venus

In preparation for the Mars Observer mission (see B.), data previously collected by the Mariner, Viking and Phobos spacecraft have been reanalysed to derive a good a priori model of the gravity field of Mars. It is hoped to verify and expand this model using the data from the Mars Observer mission. Significant improvement in the knowledge of the gravity field of Venus has been achieved as a result of the processing of the tracking data of the successful Magellan mission, which has been orbiting the planet since 1990. Comparison of the gravity fields of Mars, Venus and the Earth is expected to provide fundamental information about the interior structure and the formation of the inner planets.

F. Application of GPS to Geodynamics

During the last year, the GPS system has taken a big step towards its completion. As of December 1992 there are 20 operational spacecraft, just four satellites short of the planned constellation of 21 plus 3 operational spares. This year also marked the first operational test of a global GPS tracking network, in preparation of the establishment of an International GPS Service (IGS), as recommended by the IAG. In this test, which lasted from 21 June to 21 September 1992, an attempt was made to operate about 25

globally distributed high quality GPS receivers continuously. The data were transferred through computer networks to several processing centers, which were to generate products within a few days after the data were taken. These products consist of precise GPS orbits and earth rotation parameters. The test was highly successful and will probably lead to a permanent service in the near future. The accuracy of the recovered GPS orbits is mostly better than 1 m, which is quite an improvement over the 20 to 30 m errors in the broadcast ephemerides. The quality of the polar motion parameters is at least comparable to SLR, but the temporal resolution is much higher, due to the continuous tracking coverage.

The improved orbit accuracy and the global coverage have also resulted in much better results for the estimation of station coordinates. Global performance is now becoming comparable to SLR. For regional networks of tracking stations, like the European network with a large number of SLR and VLBI sites, the agreement with the GPS solutions has been shown to be better than 1 cm. This is of great importance for regional geodynamic studies, such as the Wegener project, which focuses on crustal motions in the Eastern Mediterranean region. GPS promises to provide a good complementary technique to SLR and VLBI, by which the temporal and spatial resolution of the geodynamic networks can be improved at acceptable cost. The biggest problem facing GPS is the data processing and analysis. More effort in standardization and coordination is needed to take full advantage of this new and promising technique.

IX. SCIENTIFIC BALLOONING

Remarkable improvements in balloon materials have been achieved by groups in France and the United States. Success rates of nearly 100 per cent have been obtained with the improved material. In the United States encouraging progress has been made in the development of polyethylene-based long duration balloon material, but also biaxially oriented nylon-6 has been further developed for a super-pressure balloon prototype.

Related activities have concentrated on developing techniques for material and stress analysis and tools for balloon engineering. A new method for balloon design has been developed in France, using pre-positioned finite elements. Low computing costs have stimulated a wide range of purely mathematical and experimental analysis techniques for balloon films and balloon envelopes. A NASA study on the internal or external placement of the balloon caps came out with a recommendation for externally capped balloons, which would allow more efficient balloon designs.

Impressive new designs of balloon instruments have been developed, mainly in the field of X-ray astronomy. A Japanese group has developed a superconducting solenoid spectrometer (BESS) to measure the cosmic ray antiproton spectrum and for high energy gamma ray astrophysics. There are feasibility studies of balloon borne

instruments for solar flare studies (Flare Genesis Project) involving a large solar telescope. The NASA balloon programme has recovered from the problems of the early 1980s. The long duration balloon project will change from a development programme into an operational capability in 1992. Recently, emphasis has been placed on the development and implementation of new support systems and facilities. A new permanent launch facility in New Mexico has been established, and a heavy load launch vehicle is under development.

Nine balloon campaigns have been supported by NASA in the past two years. The topics ranged from support of the Upper Atmosphere Research Satellite (UARS), studies of high energy astrophysics in the southern hemisphere (experiments from Alice Springs, Australia), to yearly campaigns in support of cosmic and heliospheric physics from Lynn Lake, Canada, and several long duration flights over Antarctica. From those flights NASA reported the recovery of payloads after a circumferential flight taking about 10 days. These long duration flights over Antarctica open a new possibility to perform future flights of nearly one month duration. Based on the success of these flights, NASA announced the continuation of its long term planning in this area.

Contributions to a global atmospheric data base with measurements of ozone column density and atmospheric circulation over the United States were the goals of another NASA superpressure balloon project. A first test flight was made in 1992.

Scientific ballooning in Russia has concentrated in two international projects: a joint programme with Brazil on research in the Brazil magnetic anomaly, and a cooperative programme with China on long duration flight experiments in cosmic ray physics.

India is still active in scientific ballooning. Some 420 flights have been carried out from the Hyderbad launch facility since its establishment in 1969. The emphasis of India's programme is on astronomy (X-ray, gamma-ray and infrared) and atmospheric sciences (ozone, aerosols, electric conductivity).

There has been increasing interest in activities relating to satellites to be launched in the 1990s for solar-terrestrial and magnetospheric physics. In particular, the technical aspects of possible balloon campaigns were discussed in a workshop at Spitsbergen, which was dedicated to the planning of ground-based, rocket and balloon studies to be performed in conjunction with the Cluster satellites. Campaigns involving a number of small balloon payloads which can be easily launched were seen as a valuable supplement to the ground-based campaigns being planned in the Svalbard region.

In addition to NASA's interest in long duration flights, which have many advantages because of the increasing complexity and cost of balloon payloads, France and Japan have also been very active in the long duration flight field. Most impressive were the achievements of long duration flights over Antarctica by groups from Japan

and the United States groups. The flights circulated the south pole by using zero pressure balloons which consume very little ballast, and take advantage of the absence of sunsets in the summer season over Antarctica. The National Polar Institute and ISAS in Japan have reported a successful flight where the balloon returned to the vicinity of the launching area of Syowa after two weeks. Thereafter the balloon continued its flight over Antarctica for 10 more days. In France research on a new type of vehicle, the infrared montgolfière, is in progress.

The new political situation in Eastern Europe and in Russia has triggered numerous plans for long duration flights in the northern hemisphere.

Another focal point was the subject of balloons on other planets. The Martian balloons to be launched in 1996 are under development, and a feasibility study of Venus low altitude balloons was performed by a French and Japanese group. A test experiment which utilises high altitude balloons for Mars remote sensing instruments was also conducted.

X. SPACE RESEARCH IN DEVELOPING COUNTRIES

The COSPAR Panel on Space Research in Developing Countries (PSRDC) was established in 1983. The Panel receives financial support from the ICSU-UNESCO subvention for its activities.

During 1991 and 1992 the Panel extended travel support for scientists from developing countries to participate in scientific meetings on topics relating to space research. Some of the scientists from developing countries have also received additional travel support to undergo training in space applications.

The Panel cooperated with the COSPAR Interdisciplinary Scientific Commission A (Space Studies of the Earth's Surface) at the COSPAR Plenary in Washington, D.C., United States, in August-September 1992 in organising a special session of the symposium on "Global Change and Relevant Space Observations". In addition, the Panel extended financial support for a number of scientists from developing countries to participate in the Plenary meeting.

Finally, the Panel was involved in the preparations of the United Nations Workshop on Space Technology in developing countries - "Making it Happen", which was organised by the United Nations in Washington, D.C., United States prior to the World Space Congress in August 1992.

CONTRIBUTORS

The report submitted by IAF (Part One) was prepared by Dr. Jerry Grey (for Dr. Karl Doetsch and Dr. Lubos Perek, Co-Chairmen of the International Programme Committee for the 43rd IAF Congress) and was approved by Dr. Alvaro Azcarraga, the president of IAF.

For the report submitted by COSPAR (Part Two), each of the seven Interdisciplinary Commissions and four Panels of COSPAR contributed a chapter. The following individuals prepared material for their respective Commission or Panel: Dr. A. Ghazi (Commission of European Communities), coordinator for Chapter I; Mr. M. Albani (European Space Agency), Dr. W. Grose (United States), Mrs. J. Landeau (ESA), Dr. H. Rött (Austria), Dr. J. Schmetz (Germany) and Dr. F.W. Taylor (United Kingdom), contributors Chapter I; Prof. D. Möhlmann (Germany), Coordinator Chapter II; Prof. B.E. Schultz (United States), Dr. A. Albee (United States), Dr. J. Nishimura (Japan), Dr. A. Pederson (ESA), and Dr. T.C. Owen (United States), contributors, Chapter II; Dr. E. Thrane (Norway), coordinator for Chapter III; Dr. G. Paschmann (Germany), coordinator for Chapter IV; Dr. D.E. Page (ESA) and Prof. D.J. Southwood (United Kingdom), contributors to Chapter IV; Prof. L.E. Peterson (United States), coordinator for Chapter V; Prof. J.L. Culhane (United Kingdom) and Dr. A.H. Gabriel (France), contributors to Chapter V; Dr. G. Horneck (Germany), coordinator for Chapter VI; Dr. M.A. André (France), Prof. K. Dose (Germany), Dr. E.A. Ilyin (Russia) and Dr. R.J.M. Fry (United States), contributors to Chapter VI; Dr. R. Sokolowski (United States), coordinator of Chapter VII; Dr. R. Kolenkiewicz (United States), coordinator and Dr. B.A.C. Ambrosius (The Netherlands), contributor to Chapter VIII; Prof. W. Riedler (Austria), coordinator of Chapter IX.; and Dr. K. Kasturirangan (India), coordinator of Chapter X; Dr. R.A. Harrison (United Kingdom), Editor.

ACRONYMS AND ABBREVIATIONS

AIRSAR	Airborne Synthetic Aperture Radar
ATSR	Along Track Scanning Radiometer
AU	Astronomical Unit or Accounting Unit
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AXAF	Advanced X-ray Astrophysics Facility (NASA)
BATSE	Burst and Transient Source Experiment
BOREAS	Boreal Ecosystems-Atmosphere Study
CCD	Charged Coupled Device
CDS	Coronal Diagnostic Spectrometer
CdTe	crystal Cadmium Telluride
CEC	Commission of the European Communities
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CELIAS	Charge Element and Isotope Analysis
CEOS	Committee on Earth Observation Satellites
CIGNET	Cooperative International GPS Network
CIRA	COSPAR International Reference Atmosphere
CIS	Commonwealth of Independent States
CLAES	Cryogenic Limb Array Etalon Spectrometer
CLEOPATRA	Cloud Experiment Oberpfaffenhofen and Transports
CNES	Centre National d'Etudes Spatiales (France)
CNRS	Centre National de Recherches Scientifiques (France)
COBE	Cosmic Background Explorer
COMPTEL	Imaging Compton Camera
COSPAR	Committee on Space Research
COSTEP	Comprehensive Suprathermal and Energy Particle Analyzer
CRAF	Comet Rendez-vous Asteroid Flyby
CRRES	Combined Release and Radiation Effects Satellite
CRRE	Combined Radiation and Release Experiment
CSA	Canadian Space Agency
CSTG	Coordination of Space Techniques for Geodesy and Geodynamics
CTRS	Conventional Terrestrial Reference System
CVTE	The Crystals of Vapor Transport Experiment
CZCS	Coastal Zone Color Scanner
DARA	German Space Agency
DLR	German Aerospace Research Establishment
DMSP	United States Air Force Defense Meteorological Satellite Program
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite

DPM	Drop Physics Molecule
DPM	Drop Physics Module
DYANA	Dynamics Adapted Network for the Atmosphere
EGRET	Energetic Gamma-ray Experiment Telescope
EIT	EUV Imaging Telescope
ERNE	Energetic and Relativistic Nuclei and Electron Experiment
ERS	European Remote Sensing Satellite
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EURECA	European Retrievable Carrier
EUV	Extreme Ultraviolet
EUVE	Extreme Ultra-Violet Explorer
EVA	Extra-vehicular activities
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FAO	Food and Agriculture Organisation
FIFE	First ISLSCP Field Experiment
FIRST	Far IT Sub-mm Telescope
FLINN	Fiducial Laboratories for International Natural Network
FUSE	Far Ultraviolet Explore
GAS	Get Away Special
GEWEX	Global Energy and Water Cycle Experiment
GGS	Global Geospace System
GIG-91	GPS IERS and Geodynamics
GLONASS	Global Navigation Satellite Program
GOLF	Global Oscillations at Low Frequencies
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GRO	Gamma-Ray Observatory
GSFC	Goddard Space Flight Center (NASA)
GSI	Gesellschaft für Schwerionenforschung MBH
HALOE	Halogen Occultation Experiment
HIREGS	High Resolution Gamma-Ray and Hard X-Ray Spectrometer
HRDI	High Resolution Doppler Imager
HST	Hubble Space Telescope (NASA)
HZE	Particles of high change and high currency
IAF	International Astronautical Federation
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICRP	International Commission on Radiological Protection
ICSU	International Council of Scientific Unions
IERS	International Earth Rotation Service
IGBP	International Geosphere - Biosphere Program

IGS	International GPS Geodynamics Service
IML	International Microgravity Laboratory
IOC	Intergovernmental Oceanographic Commission
IR	Infrared
IRI	International Reference Ionosphere
IRIS	International Radio Interferometric Surveying
IRS	Indian Remote sensing Satellite
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISAS	Institute of Space and Astronautical Science
ISCCP	International Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climate Project
ISO	Infra-red Space Observatory
ISO	Imaging Spectrometer observatory
ISTP	International Solar-Terrestrial Program
ISY	International Space Year
IUE	International Ultraviolet Explorer
IUGG	International Union of Geodesy and Geophysics
JGOFS	Joint Global Ocean Flux Study
JPL	Jet Propulsion Laboratory
JRC	Joint Research Centre
LADIMAS	Latitudinal Structure of Middle Atmosphere Structure
LAGEOS	Laser Geodynamics Satellite
LAGEOS	Laser Geodetic Satellite
LASCO	White Light and Spectrometric Coronograph
LDEF	Long Duration Exposure Facility
LET	Linear Energy Transfer
LISS	Linear Imaging Self-Scanning Sensor
LLR	Lunar Laser Ranging
LPE	Lambda Point Experiment
LTE	Local Thermodynamic Equilibrium
MAC	European Multisensory Airborne Campaign
MAP	Middle Atmosphere Program
MDI:SOI	Michelson Doppler Image
MHD	Magneto Hydrodynamics
MICG	Mercury Iodide Crystal Growth
MLS	Microwave Limb Sounder
MLTCS	Mesosphere, Lower Thermosphere Coupling Study
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Space Development Agency
NLC	Noctilucent Clouds
NOAA	National Oceanographic and Atmospheric Administration (United States)
NODIS	NASA Online Distribution and Information Service
NSSDC	National Space Science Data Centre

OPS	Optical Sensor
OSL	Orbiting Solar Laboratory
OSSE	Oriented Scintillation Spectrometer Experiment
PCG	Protein Crystal Growth
PLDS	Pilot Land Data System
PMSE	Polar Mesosphere Summer Echoes
PRARE	Precise Range and Range-rate Equipment
PRISMA	Probing Rotation and Interior of Stars
RAIDS	Remote Atmospheric and Ionospheric Detection System
ROSAT	Röntgen Satellite (German X-ray satellite)
SAR	Synthetic Aperture Radar
SAX	X-ray Astronomy Satellite (Italian)
SBUV	Solar Backscatter Ultraviolet
SCOSTEP	Scientific Committee on Solar Terrestrial Physics
SeaWifs	Sea-viewing Wide Field Sensor
SERC	Science and Engineering Research Council
SETI	Search for Extraterrestrial Intelligence
SIL	Sudden Iron Layers
SIRTF	Space IR Telescope Facility
SLR	satellite laser ranging
SLS	Spacelab Life Sciences Mission
SMM	Solar Maximum Mission
SMY	Solar Maximum Year
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SOLSTICE	Solar Stellar irradiance comparison Experiment
SPOT	Satellite pour l'observation de la terre TMLF
SRDC	Space Research in Developing Countries
SSCE	Solid Surface Combustion Experiment (NASA)
SSL	Sudden Sodium Layers
SSMI	Special Sensor Microwave Imager
STDCE	Surface Tension Drive Convection Experiment
STEP	Solar Terrestrial Energy Program
STS	Space Transportation System
SUMER	Solar Ultraviolet Emitted Radiation
SUSIM	Solar Ultraviolet Spectral irradiance Monitor
SWAN	Solar Wind Anisotropies
SXT	Soft X-Ray Telescope
TDRSS	Tracking and Delay Relay Satellite System (NASA)
TIMS	Thermal Infrared Multispectral Scanner
TIROS	Television and Infrared Observations Satellite
TM	Thematic Mapper
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment

TREES	Tropical Ecosystem Environment observation by Satellites
UARS	Upper Atmospheric Research Satellite
UCWE	Upper Coupling of Wave Energy
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
URSI	International Union of Radio Science
USML	US Microgravity Laboratory
USMP	United States Microgravity Payload
UT	Universal Time
UV	Ultraviolet
UVCS	Ultraviolet Coronograph Spectrometer
VCGS	Vapor Crystal Grercury Iodide Crystals
VIRGO	Variability of Solar Irradiance
VLBI	Very Long Baseline Interferometry
VSOP	VLBI Space Observatory Program
WCRP	World Climate Research Programme
WDC	World Data Centre
WEGENER	Working Group of European Geophysicists for the Establishment of Networks for Earthquake Research
WINDII	Wind Imaging Interferometer
WMO	World Meteorological Organisation
WOCE	World Ocean Experiment
XMM	X-ray Multi-Mirror
XTE	X-ray Timing Explorer